Electrical Engineering

February
1936

Published Monthly by the
American Institute of Electrical Engineers

A E E I

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American Institute of Electrical Engineers

(Founded May 13, 1884)

Electrical Engineering

Registered U. S. Patent Office

February 1936
Volume 55
No. 2

The Official Monthly Journal and Transactions of the A.I.E.E.

UBLICATION OFFICE, 20th and Northmpton Streets, Easton, Pa.

DITORIAL AND ADVERTISING OFFICES, 3 West 39th Street, New York, N. Y.

MAIL should be sent to New York address

NTERED as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted or mailing at special postage rates provided r in Section 1103, Act of October 3, 1917, uthorized on August 3, 1918.

UBSCRIPTION RATES—$12 per year to nited States, Mexico, Cuba, Porto Rico, awaii, and the Philippine Islands, Central merica, South America, Haiti, Spain, and panish Colonies, $13 to Canada, $14 to l other countries. Single copy $1.50.

HANGE OF ADDRESS—requests must be ceived by the fifteenth of the month to be fective with the succeeding issue. Copies ndelivered because of incorrect address canot be replaced without charge. Both old d new addresses should be given, as well as y change in business affiliation.

DVERTISING COPY—changes must be reived by the fifteenth of the month to be fective for the issue of the month succeeding.

ECTRICAL ENGINEERING is indexed anally by the Institute, weekly and monthly *Engineering Index*, and monthly by *Indusal Arts Index*; abstracted monthly by *Science ostracts* (London).

inted in the United States of America. umber of copies this issue—19,000

This Month—

Front Cover

San Francisco-Oakland Bay Bridge at night, as seen when looking across the west channel from Yerba Buena Island, with San Francisco in the background. Electric power is playing a vital part in the building of this great bridge, a total connected load of some 18,000 horsepower supplying power for spinning the cables and meeting other power demands of the builders, as well as for lighting and communication purposes.

Photo courtesy General Electric Company

Special Articles

A.I.E.E. Papers

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Discussions

The 1936 Summer Convention, Pasadena California June 22-26

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On the Pacific Coast for the first time, the summer convention this year offers unusual opportunities for turning a convention trip into a vacation trip. At the left is shown the west façade of the high voltage laboratory at California Institute of Technology

In This Issue—

FROM the present paralysis of economic agencies and clogging of economic channels, engineering education can scarcely escape modification with regard to its social attributes, even though it should remain unaltered as individual scientific training. Thus spoke the president of an eastern university at a recent meeting of the Society for the Promotion of Engineering Education (*pages 132–6*).

ROTATING electric machines connected to overhead circuits require protection from lightning whether or not a transformer is interposed between line and machine. Various methods of protection have been proposed upon theoretical considerations; tests to determine the effectiveness of these methods are reported in this issue (*pages 137–44*).

OPERATIONAL calculus is being applied more and more to the solution of engineering problems, and hence many attempts have been made to broaden its application. In this issue, a method has been applied to the operational solution of electrical networks, wherein the initial conditions may be either rest or dynamic (*pages 158–64*).

INDUCTION motor design is said to have passed into the period in which revisions and refinements in design methods are being made. A refinement in the calculation of secondary resistance is presented in this issue, with particular attention to the radial width of resistance rings connecting the ends of the rotor bars (*pages 144–50*).

DISCUSSIONS of A.I.E.E. technical papers have been eliminated from the 3 preceding issues in order that all 1936 winter convention papers might be published in advance. Some of the discussions that have accumulated in the meantime are published in this issue (*pages 167–209*).

STANDARDS for inspection and tests of electrical equipment for use in hazardous locations have been developed to the stage where an accurate prediction can be made as to whether or not certain equipment can be operated safely where flammable liquids or gases are present (*pages 151–8*).

UNSTRESSED cable lengths were calculated, measured, and cut to be continuous over 3 spans having a total length of almost 5,000 feet, in designing and constructing a transmission line crossing over the St. Lawrence River (*pages 164–7*).

THE 50th anniversary of the establishment of the a-c system in America will be observed appropriately by special meetings to be held by the majority of the Institute's 61 Sections (*page 210*).

THE Institute's 1936 winter convention is getting under way as this issue goes to press. A complete report of this event is scheduled for inclusion in the March issue.

Effective Co-ordination

—A Message From the President

RECENTLY I had the pleasure of attending the annual meeting of the American Engineering Council held at the Mayflower Hotel, Washington, D. C.

The majority of members of the Institute are familiar, I believe, with the development of American Engineering Council from the time that a joint body, Engineering Council, was created by the 4 Founder Societies in 1917 for the purpose of establishing an agency to deal with matters of common interest to engineers and to serve as an instrument for contact between engineers and the general public in so far as such matters concern the engineering profession and the public welfare. Fundamentally, this body provides the means whereby unified action may be taken when necessary, either to promote a more enlightened public opinion, or to safeguard in a proper way the interests of the members of the engineering profession.

The first day's session, held on January 9, was devoted to a conference of secretaries of engineering societies, on which occasion matters pertaining to national, state, and local interests were discussed. At the luncheon Col. J. M. Johnson, assistant secretary of commerce, spoke on "The Engineer in Government and Business."

The session on the second day included a discussion of the economic status of the engineering profession, and at luncheon the delegates were addressed by Charles W. Eliot, II, executive officer of the National Resources Committee, on the subject "Economic Uses of Natural and Human Resources." At the afternoon session the delegates discussed the various reports of the public affairs committee.

The All Engineers Dinner, with Dr. J. Francis Coleman presiding and Dr. Harrison E. Howe toastmaster, held in the ballroom of the Mayflower Hotel, was attended by over 600 engineers. Dr. William F. Durand, of Stanford University, past-president of the American Society of Mechanical Engineers, John Fritz Medalist 1935, and chairman of the Third World Power Conference, gave a most interesting and instructive talk on "Why the Engineer." Ralph E. Flanders, past-president of the American Society of Mechanical Engineers, spoke on "A Realistic Concept of the Engineer in Government." Other guest speakers were the presidents of several of the national engineering societies. The retiring president, Dr. J. Francis Coleman, was presented with a scroll expressing the appreciation of the membership for his untiring and able efforts during his term of office, which embraced probably the most distressing period in the history of the engineering profession.

The session on the third day consisted of a business meeting, followed by the president's luncheon. Dr. A. A. Potter, dean of engineering, Purdue University, and past-president of the American Society of Mechanical Engineers, was elected to fill the office of president of the American Engineering Council for the next 2 year term. That there are many exceedingly important movements which require engineering guidance is evident to anyone conversant with present-day affairs, and the engineering profession is to be commended for its choice of Dean Potter, who is a most able, enthusiastic, and inspiring leader, as the head of the Council.

From the beginning, the ideals and purposes of the American Engineering Council have been set on a high plane of public service. While it has not assumed that engineers were alone in their ability to render such service, Council has sought in its findings and recommendations, to be nonpartisan, unbiased, and guided in the expression of opinions by facts and experience. In such fundamental reports as "The Studies of Wastes in Industry," "The Twelve Hour Shift in Industry," and similar inquiries, it has attempted to present workable answers to the economics of a changing world without being called "capitalistic" or "socialistic" by those who may differ in the interpretation of the facts as found. During the 15 years of its existence it has built up a good will and reputation for nonpartisanship which can be counted as a primary asset not only to the profession and the governmental authorities, but also to the public, which both the engineering profession and the governmental representatives serve.

Committees have sought to express the considered opinion of engineers not only on questions involving specific legislation, but also on broad governmental policies, such as government organization, the merit system, the employment status of engineers in government, and many others. The rapid expansion of government agencies in fields of engineering development in the past 2 or 3 years has added another function, namely, that of serving as an "embassy of engineers" available for counsel or advice on problems of organization and personnel of newly formed agencies of which engineering practice or engineering personnel are a part.

Only through the deliberations of such a body can the best interests of the great profession of engineering and of its members be served and procedure formulated under which engineers may make their greatest contribution to all constructive and forward-looking movements. Both moral and financial support therefore should be given to the Council to enable it to continue to exert its broad influence properly toward maintaining the integrity and well-being of the profession to the ultimate benefit of all its members.

The work that the American Engineering Council has done in the past and the functions planned for the future as presented at its annual meeting give substantial evidence of the importance of its work. The members of the Council are well-qualified representative engineers under competent leadership, and we may be assured that they will ever strive to uphold the high ideals and purposes originally established in serving the best interests of the engineering profession.

The New Epoch in Engineering Education

By C. C. WILLIAMS, President S.P.E.E.*

In this address,[1] republished here at the request of the Institute's committee on education, the author constructively looks ahead, discussing frankly the probable status of engineering education (and the engineering profession) in the post-depression era and suggesting adjustments in curricula to suit new conditions. He says "there is no reason to predict a surplus of engineers when there is no diminution in the need for engineering services—man's wants are illimitable, if engineers have but the discernment to discover and the ingenuity to satisfy them."

ONE of the time-honored tenets of philosophy is that the affairs of this universe consist of causes and effects, that a phenomenon is always followed by an effect, that there is never an event without a cause, and that an effect is commensurate with its cause. To the extent that this tenet is valid we may reasonably expect a disturbance so catastrophic in its proportions as the present great depression to produce momentous effects in those spheres which it touches. The extent to which engineering, and indirectly, engineering education, may be modified is a matter that may well engage our attention. Recognizing the urgency of this question . . . . . I purpose at this time to comment on 2 aspects of the matter: (1) the adjustment in curricula to suit new conditions, and (2) the probable status of engineering education in the post-depression era.

In so far as educational processes consist of cultivating the student's power to think and his facility in expressing his thoughts, the results are applicable in any environment, and happily the bulk of the education process is of this enduring character. However, because the transfer of mental disciplines is limited, and because applied science offers as good exercises for thinking as does ancient lore, in addition to storing the mind with usable information, engineering education employs practical science in its processes. Hence, it is not of the cloister, but of the world of affairs—"a product of industrial, social and political life and ideals," to quote Professor Scott's admirable report. Furthermore, in recent decades, the engineering profession has been gradually shedding its strictly technical chrysalis and emerging as one of the dominant influences in shaping economic affairs, and every new application of mechanical energy extends the circuit of its influence. Engineering education has been so drawn out of its isolation that the absence of change in the pattern following the crises of '73, '93, and '07 does not prove that none will occur now. On the contrary, from the present paralysis of economic agencies and clogging of economic channels, engineering education can scarcely escape modification with regard to its social attributes, even though it should remain unaltered as individual scientific training.

If before proceeding with any forecast of the new epoch, we glance back for a moment at the mileposts of the past in order to find the measure of an epoch, we observe that the century covering the development of engineering education in America is divided naturally by certain notable events into 3 fairly equal periods, each of which exhibits rather distinctive characteristics.

The first epoch would be placed readily as the interval between the founding of engineering instruction at West Point and Rensselaer, about the close of the first quarter of the last century, and the passage of the Morrill Act in 1862. It may be called the "Epoch of Beginnings." The second epoch extends from the Morrill Act to the founding of the first engineering experiment station in 1903, and may be given the caption "Curriculum Building." In this period, the undergraduate curriculum took form and the main branches of engineering became differentiated and recognized; the scope and character of engineering were essentially determined by men in field and shop, the professor endeavoring to impart a knowledge of practice to his students as best he might; the required preparation for the engineering instructor beyond graduation consisted of practical experience in field or factory; and graduate study was almost unknown because 4 years brought the student to the limit of engineering knowledge as presented in the textbooks.

The third epoch spans the interval between the first experiment station in 1903 and the present great depression, and may be called the "Epoch of Research." In this period research profoundly affected engineering education, both as to underlying philosophies and as to procedures. Efforts to teach engineering practice was largely discontinued, emphasis being shifted to fundamentals and to the research method of approach. Engineering became investigative as well as applied science. In fact, during the last 2 decades of this epoch, investigations in engineering laboratories have been so comprehensive and thorough that frequently the research potential has actually been higher at the applied science pole than at the pure science, or "curiosity pole," with the result that the current of new knowledge has flowed from the former to the latter about as often as in the reverse direction. Experiment stations, or similar research agencies, have been set up at practically all the better equipped engineering

* At the time of delivering his address, Dr. Williams was dean, college of engineering, The State University of Iowa; since, he has become president of Lehigh University, Bethlehem, Pa.

1. Presidential address delivered at the 43d Annual Meeting of the Society for the Promotion of Engineering Education, Atlanta, Ga., June 24–27, 1935; republished by special permisssion from the *Jl. of Engg. Education*, Sept. 1935.

schools, and research departments provided on an elaborate scale in the larger industries. Research has become a word to conjure with, a cogent catch word in sales talk. It has become the most used word in the literature, and perhaps the most abused word. In this period, graduate study crystallized out from research and assumed a prominent rôle in most institutions, and graduate degrees have become a further qualification for the young instructor. In view of these facts, we may say that research has been the dominant influence in the third epoch.

The fourth epoch in engineering education, entrance to which seems likely to be hastened by the depression, can be forecast only from facts and trends now either apparent or discoverable, and manifestly, treading in the realm of prediction, proceeds with less assurance than along the plotted paths of history. The depression not only marks the beginning of the new epoch, but it yields a clue to its characteristics, because the lashings of the economic storm have revealed certain weaknesses which years of fair weather would not have disclosed. Inasmuch as the most obvious defects in engineering of the past decade are observed to lie in the economic sector and as certain new conditions now growing up which engineering will be required to meet also lie in that same sector, we may appropriately call this new era in engineering education the "Epoch of Economic Adjustment," recognizing, of course, that research and other values previously developed will continue.

That the defects and inadequacies of engineering which have appeared in the severe testing of the past 5 years are found in its economic commissions and omissions scarcely requires demonstration. Despite the fact that our radios still growl and fade, our automobiles are irresponsive on cold mornings, our concrete floors crack, and a few tragic accidents have occurred, the short-comings of technical engineering are now fundamental, and by the same token, engineering education, in its technical aspects, has disclosed no radical faults. The areas in which engineering and engineering education have fallen short of their responsibilities are in such matters as unsound valuations for securities, overbuilt industrial plants, lack of diversification in manufactures, railroad improvements contemplating increased traffic that could not materialize, technological unemployment, ill-conceived labor relations, vulnerable centralization of industry, and misjudging of social trends. Not all these weaknesses have developed within the purview of engineering as now defined, but they represent management wherein engineering techniques might properly be applied. Hence, it seems reasonable to expect engineering education to expand gradually into those areas in order, first, to strengthen engineering administration wherein it now includes these matters, and second, to offer preparation for assuming those functions wherein other agencies have been proved incompetent. There lies with engineering the responsibility for the economic control and stability of its own affairs and if that responsibility is not recognized and accepted, engineering education to that extent must be adjudged wanting.

A conspicuous example of the economic maladjustment of engineering curricula is found in their lag behind the specializations resulting from the various technical devices available for home, office, shop, and construction operations, which require a measure of technical knowledge and organization for their distribution and application. Engineering education has become cumbered and choked to a degree by its own output. Large engineering projects no longer represent details designed by a master engineer and his staff; they are rather an assembly of specialties which have been developed by the experts in manufacturing concerns. Training for the technical production as well as for the distribution and application of these devices justifies educational preparation. At the present time colleges of commerce and departments of science vie with engineering schools in this field. Combination courses in engineering and commerce usually have resulted in a mixture of the water of science with the oil of business rather than a homogeneous preparation suitable for the purpose. Since we cannot shorten this giant growth of engineering specialization to fit the procrustean bed of last century's formula of engineering education, we shall have to enlarge the bed.

Many engineers, sensing the need for an adjustment to provide for these miscellaneous technical and administrative specializations, have urged a broadening of engineering preparation by the introduction of various subjects and even of new curricula. To most of us who are directly responsible for administering college curricula, however, this procedure has seemed impracticable, because if such material should be included formally, the course either would have to be extended beyond 4 years, or cease to be genuine engineering. Neither can an indefinite number of kinds of engineering curricula be provided to lead to all of these technical specialties. Dean Hoover, in the February 1935 issue of the *Journal of Engineering Education** listed 337 vocations emanating from these specialties to which the title engineer had been appended, and even then the list is not exhaustive, new lines appearing every year. It is significant that the largest engineering school in America has confined its major curricula to the chemical, civil, electrical, and mechanical divisions. These 4, with mining and metallurgical engineering and perhaps 1 or 2 others added in some places, would seem to suffice at present for main trunk curricula, leaving the miscellaneous specializations to be treated as branchings rather than as co-ordinate stems, and to be provided for in postgraduate years, even if not as graduate work.

Instead of diluted main curricula, and numerous minor ones, courses in applied science supplementary to engineering curricula, have had a few tryouts with particular objectives in mind, but the possibilities in this direction have not been fully explored. Many educable young men, desiring to enter commercial fields involving engineering specialties, are not much interested in engineering as a creative profession, yet they desire a scientific education of a sort not offered by liberal arts faculties. Institutes of technology, colleges of applied science, and even schools of engineering with a more restricted scope, are the most suitable agencies extant to administer such ap-

* See also Dean Hoover's article, "Structure of the Electrical Engineering Profession," ELEC. ENGG., July 1935, p. 695–9.

plied science courses. They need not have the designation of any variety of engineering and might be as non-committal as A.B. in arts or B.S. in pure science. They would merely constitute a good college education in applied science and would presumably provide a wide range of electives with a view to cultivating a maximum of individual resourcefulness. The innovation would be similar but not quite parallel to the introduction of the elective system in the liberal arts colleges half a century ago, since colleges of engineering would sponsor these supplementary courses much as arts colleges at that time added science to their classical curricula. It is quite within the range of possibility that through the operation of these supplementary applied science courses, certain vocations now considered as trades might ultimately be elevated to the peerage of polite professions, entitled to the trappings of prerequisites and college degrees.

Instead of one pure type of engineer, therefore, we may come to recognize about 3 varieties of the species: engineer *alpha*, engineer *beta*, and engineer *gamma*, to use the customary designations of variations from type. Engineer *alpha* would represent the highly trained technical genius, prepared through graduate study and otherwise to do advanced developmental work; engineer *beta* would be the typical routine designer and administrator commonly produced by the present undergraduate courses; engineer *gamma* might not be an engineer at all in the ingenious inventor sense, although he might be best equipped to do the accessory work that he intends to follow. Occasionally, he might develop into a technical engineer even as arts graduates have done not infrequently. Generally he would perform a liaison function between technical engineering and human wants. Socially and politically all 3 groups might continue their associations together advantageously, although educationally and legally separate categories might be recognized. Economics should permeate the training of engineer *gamma* and should flavor more than previously that of all engineers.

Advocating economics content in engineering education does not imply a proposal to extend the time devoted either to classic economics or to branches now within the proper domain of colleges of commerce. Much of the former is too hypothetical to serve the more quantitative requirements of engineers, and further, there is no justification for overlapping or encroaching upon those phases of economics that lie within the recognized sphere of colleges of commerce. The applications of economics of which I speak cover those social phenomena and principles of management inherently connected to manufactures, to public service, and to the construction industry. For the sake of simplicity, we might, for the purposes of this discussion, invent a new word to denote this field. The word "technonomics," which etymologically would mean the orderly management of technical affairs just as economics means the orderly management of a farm or business, may be used for this purpose. "Technonomics," as applied social science, would employ engineering methodology such as thoroughness of analysis, rigorous scrutiny and test of new proposals, strict evaluation of the so-called "economic laws" before applying them, conservatism in design and planning, and insistence on economic justification as a condition precedent for most public works. It would recognize corporations as proper agencies of modern economic democracy; it would contemplate a self-governing industry, including the related labor organization; and it would proceed on the assumption of a reasonable employment security for the worker. The time may be not far distant when schools suitably circumstanced will set up "technonomic" experiment stations or institutes of "technonomic" research to test old dogmas and to seek new knowledge that will advance related economic practices comparably with technical achievement.

The depression has disclosed a need for "technonomics" in planning public works that will add to social benefit without stifling private enterprise. "Technonomics" will be needed more and more in scientific bureaus and in regulatory commissions, and all governmental functions—city, county, state, and federal—are becoming increasingly involved in technical operations. For these functions, engineering education must be socially enlightened.

From the depression is emerging a recognition of the potency of technical productivity to restore and maintain economic "normalcy." The current press frequently quotes opinions to the effect that television, air conditioning, or some other novelty will prove to be the new development that will overcome the depression. It will probably be none of these alone, but rather the marketing of numerous new specialties, that will stimulate buying and thus start the wheels of industry. The Brookings Institution, and perhaps others, have pointed out that people have invested disproportionately in securities, thereby encouraging undue plant expansion, and that this situation has produced a lack of balance between fixed capital and liquid funds available for purchase of consumable goods. Why? Because, the market for the ordinary had become saturated, and there were no new attractions to tempt the purse. An economy of plenty, evidently, can be kept in balance as between invested and liquid capital only by devising new conveniences which people will buy in preference to investing with a view to future leisure. If this be true, then the inventive genius of the engineer in creating such goods will play an increasingly important part in our future economic weal, and the significance of this fact should be considered in the engineering education of the future.

The depression has also revealed evidence of a "technonomic" error: that, by pointing our educational policies too exclusively toward large scale industry rather than to developing resourcefulness and inculcating an interest in establishing new enterprises on a small scale, we have not only limited the opportunities for our graduates, but we have contributed to economic lopsidedness. Instances might be mentioned of small scale manufactures, founded by engineering graduates, which have weathered the depression more successfully than larger industries. Such enterprises have made the communities affected self-sufficient to an extent, and they give these self-contained areas a stability capable of halting the spread of economic demoralization in times

of crises. The superior industrial stability of France and certain other European countries is attributable, in part at least, to the numerous small industries that tend to localize the economic activities of the towns involved and make them independent of the currents that flow between metropolitan centers. The economic adjustment of engineering education will take into account this principle of balanced employment and of diversification, not only with a view to increased opportunities for graduates but also as a factor in the public prosperity.

Perhaps the more perplexing doubt in the minds of some pertains not to what effect the depression may have on the curriculum in the new epoch, but rather to what effect it may have on the future of engineering itself. In the rebuilding of economic systems, will engineering play a larger or a smaller part than in the past? In the acid test of the depression, where social institutions are tried as well as men's souls, to what extent will engineering have been found fundamental and necessary for the rehabilitation?

A few engineers have expressed pessimistic forebodings relative to overcrowding and lack of opportunities in the future. I do not share that view. Instead, my own observations lead me to optimism and confidence. There is no reason to predict a surplus of engineers when there is no diminution in the need for engineering services, the present unemployment to the contrary notwithstanding. Nature's resources, which the engineer diverts for the use of man, are not approaching exhaustion, and man's wants are illimitable, if engineers have but the discernment to discover and the ingenuity to satisfy them. Improving personal conveniences as well as social intercourse and public welfare will make increasing demands on applied science. Also, because of the technical activity in Europe, Latin America, and the Orient, any reasonable hope for regaining foreign markets in world competition has a firmer basis in the fertility of applied science than in the maneuverings of politics. Hence, unemployment of engineers results from underconsumption rather than from overproduction. There can be no surplus of engineering service so long as thousands of accidents occur daily on highways and in industry; so long as conflagrations destroy many lives and millions in property; so long as floods run rampant over town and countryside; so long as noise and dirt in cities impair physical and mental health; so long as electric lights are but 5 per cent efficient and the illumination supplied is but a fraction of the need; so long as power transmission is limited to a short radius; so long as public service rates require regulation; so long as cities are ugly and inconvenient; so long as enormous waste exists in coal, oil, and gas production; so long as most of the energy of fuel is lost in the conversion; so long, *in fine*, as man's personal and social welfare can be further promoted by exploitation of nature's riches. Superior skill in performing these services only is needed to yield an expanding demand for engineers.

This judgment is supported by a statistical study of professional growth. When graphs are drawn for other professions showing the number of practitioners in the United States per million population at the successive censuses, such graphs show a fairly constant ratio through the years. For engineering, on the contrary, the graph rises at a steep slope showing a marked and fairly constant increase in the ratio of engineers to population. Thus in 1880 there were 200 per million inhabitants, in 1890, 600; in 1900, 700; in 1910, 1,000; in 1920, 1,250; and in 1930, 1,750. The notable increase results, of course, from the great expansion of the profession in various branches and from the growth in scientific knowledge. Graphs showing social trends do not make sharp angles, hence, we might expect this graph to continue its upward direction even if at a diminished slope.

A second analysis further supports the conclusion. By determining from standard life tables the total mortality in each of the various professions, the number of annual replacements caused by death was ascertained. The average annual increase over the past 20 years was taken as an index of new positions resulting from growth in services by the profession. The sum of these 2 figures indicates the total number of openings in each profession per year under normal business conditions. This figure was then divided by the number of annual entrants to obtain the ratio of the probable number of positions to the number of entrants. These ratios were as follows: medicine, 1.00; dentistry, 1.78; architecture, 1.17; law, 0.70; and engineering 1.68. In medicine, dentistry, and law, these figures are consonant with other data collected by men in those fields. If this procedure is valid, we should conclude that with the field enlarged as suggested in the foregoing paragraphs, we may expect a 68 per cent increase in the annual demand for engineers in the first years of normal operations.

The phenomenal growth in engineering in the past is not surprising in the light of the achievements in promoting individual convenience and public weal. By means of engineering, men ride swiftly on land, on water, or in the air; the nation is bound together by strands of wire, bands of steel, and ribbons of concrete that reduce social intercourse to that of a neighborhood; one lifts his telephone and the civilized world awaits his call; pictures are flashed to newspapers; by engineering, the President of the United States chats intimately with us at our family fireside about affairs of state, the leaders of the world proclaim their messages of comity to all nations, and choice programs of artists are carried to our homes; by engineering, burdens are shifted from flesh to steel, mechanical servants attend us, eliminating child labor and allowing leisure for education and enjoyment; by engineering, lustrous fabrics come from the loom without the slow travail of the silk worm; by engineering, cities are made healthful, foods improved, and standards of living advanced. Will that current of progress slacken or diminish when there is no exhaustion of Nature's resources, when the needs of men are unlimited in variety, and when the usable scientific knowledge is ever increasing?

I think not. After these years of disorder have passed, when normal procedures shall have been restored whereby industrious men may freely exchange their labor for necessities and comforts, when skill, thrift and diligence again shall be accounted as virtues, and when investments can be made with confidence in the integrity of political institutions, the march

will be resumed. Every year, a million educable young men arrive at the age of vocational choice with the regularity of the lines of a marching army, and that eager approach of aspiring young men will neither cease nor lessen. They comprise a crop that can neither be plowed under nor limited by subsidy. At present, over 20,000 annually seek entrance to colleges of engineering and that number is growing. What engineering will become will not be determined by the needs and openings that we of this generation see in the industry ahead; it will be limited only by the abilities and purposes of that never ceasing stream of young men approaching our doors. Industry of today will not shape their destiny; on the contrary, they will fashion industry of tomorrow. To ascertain and to cultivate their individual potentialities is the prime problem of engineering education. Moreover, when an ambitious youth with a God-given ability and aspiration to be an engineer seeks admission to the profession, there is no group nor guild of men that has the moral right to deny him entrance, merely because the profession seems crowded and competition is already keen. He has a right to his chance as well as any man already in practice. Merit alone must determine who will be engineers. Even if all who graduate do not find places in engineering, my faith in the virtues of engineering education, with its ideals of thoroughness, efficiency, service, and honesty, leads me to believe that it is unsurpassed as preparation for living in this twentieth century civilization, and that, in view of the many public issues of a technological character, we are in no danger of social impairment from having too many citizens with an engineering education.

Furthermore, various studies have shown that engineering is the field that attracts many of the ablest and most virile of oncoming youth. They recognize that in science and invention lie those unexplored domains wherein discovery, giving right of possession, promises rewards for the discoverer and benefit to mankind. They are the modern frontiers and the El Doradoes that challenge the spirit of the adventurer. With physical frontiers gone, the new resources of the nation are mental rather than metal, to be dug from minds rather than from mines. Hence, engineering education must be adjusted to the new economy in order not only that individual young men may find college offerings suited to their aptitudes and inclinations, but also that society itself may keep on an even keel in the varying currents of a scientific age.

That this view is not wholly the result of a natural bias of thought on my part is indicated by the following quotation from a recent book in the field of political science, "Government and Technology," by William Beard. "The functions of industrial society and government are so largely technological in character that the engineer will, whatever his personal views, occupy a central position in the future; his science will become more and more indispensable to the conduct of government and to the stability of society. . . . (But) the challenge of the new age to engineers is still open and will long remain open. It is to be hoped that the rising generation of engineers will face that challenge boldly and aptly apply the indispensable instruments of their science—rationality and efficiency—to both government and industry."

In conclusion, the economic adjustment of engineering education pertains not only to personal careers but also to the social placement of the profession. The bulk of undergraduate education will continue without radical change, because it accords with a certain range in the natural aptitudes and interests of youth and because it is sufficiently flexible to meet changes within its scope. That scope needs to be enlarged, however, to include a surrounding zone of vocations where a maximum of adaptability will be required. If I were to mention a physical structure symbolic of engineering education in the new epoch, it would be a building somewhat like the Empire State Building in form. The main body of the building would represent the substantial bulk of our present curricula and procedures, serving well an existing and continuing need. Rising above this would be a tower of smaller plan representing graduate study for highly technical engineering. The feature most suggestive of the proposed economic adjustment would be the divers approaches and services linking the building to the world of business and living. If these last be made adequate, every room and floor of the building will be utilized advantageously.

It seems to me that the new epoch in engineering education is opening with a rosy tint at the horizon, for amidst the general devaluations of the present period, technical engineering stands at par, and the new era promises yet greater opportunities through expansion into adjacent areas where the depression has shown the need of engineering methodology. The "finale" of Professor Scott's fine report* on the great work by the Board contains the statement, "And now we come to the close of another chapter." I am not sure whether that sentence stands at the close or at the opening of a chapter. It may be at the close of a chapter but at the opening of an epoch. It reminds me of an incident that occurred near the end of the great constitutional convention in 1787. The venerable Franklin arose after the final adoption, and referring to the figure of a half sun with darting rays that decorated the back of the Speaker's chair, said: "As I have sat here following the deliberations of this convention, my gaze has frequently fallen upon the figure on the back of the Speaker's chair. At times, I have been uncertain whether it represented a rising or a setting sun. Now, Sir, I am convinced that it represents a rising sun, and that the sun of this nation, under this new constitution, is rising to a more glorious day."

In a similar way, I believe that the sun of our profession is in the ascendant, and that in the new epoch with a restoration and strengthening of economic agencies, engineering education, adjusted in its scope and objectives to meet the new conditions, will attain higher levels and will prepare even greater numbers of ambitious young men to attain the goals of their choice and to enjoy the high privilege of effective citizenship in a scientific civilization.

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* "Reports of the Investigation of Engineering Education 1923–1929," published by the Society for the Promotion of Engineering Education, and reporting the results of an intensive study conducted by the board of investigation and co-ordination of the S.P.E.E. under chairmanship of Dr. Charles F. Scott. The report is published in 2 6 by 9 inch volumes and contains some 1,670 pages. A news item calling attention to the availability of the report and indicating the nature of its content appeared in the June 1935 issue of ELECTRICAL ENGINEERING, pages 679–70.

Tests on Lightning Protection for A-C Rotating Machines

Supplementing theoretical studies on the protection of a-c rotating machines against impulse waves and previous tests on individual protective devices, a comprehensive series of tests on over-all protective schemes has been made. As a result, definite conclusions are drawn regarding the proper lightning protection for machines connected directly to overhead lines or connected through transformers, giving consideration to the type of transformer connection. Considerable information also is obtained on the propagation of surges through windings, and on the surge impedances of machine windings.

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THE response of rotating a-c machines to lightning transients was first described in 2 papers presented at Toronto in 1930.[1,2] These original papers pointed out the vulnerability of machine insulation to lightning and the need for protective capacitors, as well as arresters, to control the transient distribution of voltage in the machine so that various parts of the machine winding would not be overstressed.

The suggested methods of protection were for machines connected directly to exposed overhead circuits, as there was still considerable to be learned concerning the passage of surges through transformers. In 1932 a paper[3] was presented which showed that power transformers are not the barriers to lightning transients they were once thought to be and that rotating machines having transformers between them and the exposed overhead circuits also required protection.

The economies and practicability of providing protection by means of arresters, capacitors, and inductors were studied and a paper[4] was presented in 1933 giving a logical solution to this protection problem. Methods were proposed for protecting machines not only with direct exposure but also those connected to lines through transformers. Two other papers[5,6] have been written on the effects of transient voltages on rotating machines and means for protecting against these voltages.

The protective methods which were previously given were based mostly upon theoretical considerations. Tests had been made with the individual protective devices on some rotating machines but no tests were reported as having been made on the overall protective schemes.

The purpose of this paper is to review briefly previous material in regard to lightning protection of rotating a-c machines and the propagation of surges through their windings so as to give the background for the present tests; to give test results, (*a*) on the effectiveness of lightning protective equipment in alleviating the stresses in machines and (*b*) on the propagation of the impulses through the winding; and to give some additional information on machine surge impedances.

Laboratory Tests

Tests were made in the laboratory in Schenectady, N. Y., on a turbine generator rated 12,500 kva, 6,600 volts, 60 cycles, 3,600 rpm. This generator had a one-circuit single-turn winding consisting of 18 coils per phase connected in wye. Taps were provided on every other coil so that the internal voltages throughout the winding could be investigated.

Propagation tests were made with 1 x 5.6 and 1.5 x 33 microsecond waves which had 10 kv crests. These 2 waves were chosen because they closely approximate the 1 x 5 and the 1.5 x 40 A.I.E.E. waves and either could be obtained at will by only a slight change in the connections to the impulse generator.

Tests on the protective schemes were made with as near vertical-front flat-top waves as it was possible to obtain in order to make the tests as severe as possible.

Lightning Protection—Machines Directly Connected to Overhead Lines

For machines connected directly to overhead lines, the protective equipment which usually proves to be the most economical and still provides protection, consists of protective capacitors and special station type arresters (when required) at the machine terminals, and line type arresters at approximately 2,000 feet from the station on each outgoing line. The purpose of the line type arresters is to reduce the energy of the incoming traveling wave so that the capacitors at the machine terminals can be of a reasonable size and cost.

For grounded neutral machines, a capacitor with a minimum of 0.1 microfarad per phase is usually sufficient for the turn insulation. If the minimum size is used, it is usually advisable to have a station type arrester in parallel with it. For ungrounded neutral machines, a larger capacitor having at least 0.5 microfarad or more per phase, is needed to protect the turn insulation and to keep the neutral reflected

A paper recommended for publication by the A.I.E.E. committee on electrical machinery. Manuscript submitted July 9, 1935; released for publication Oct. 2, 1935.

The author acknowledges the assistance of W. J. Rudge, C. M. Foust, and N. Rohats, all of the General Electric Company, as well as the co-operation of several departments of this company.

1. For all numbered references, see list at end of paper.

voltages to safe values. With a 0.5 microfarad capacitor at the terminals, a station type arrester is usually not considered necessary because a capacitor of this size reduces the magnitude as well as the front of the traveling wave passing the line type arresters.

Tests on Protective Equipment for Machines Directly Connected to Overhead Lines

In the tests made to measure the effectiveness of these protective schemes, the test circuit consisted of a surge generator, a line type arrester, a resistor of 250 ohms, station type arresters and capacitors, and the generator winding. This was a laboratory equivalent circuit for an installation where there is a transmission line which has a surge impedance of 250 ohms between the line arresters and the station protective equipment. A low value of line surge impedance was chosen to simulate the condition of surges reaching the machine from over 2 lines simultaneously, and also a low value gives pessimistic results because the higher the surge impedance is, the better the protection obtained.

In order to simulate a distributed circuit of a real line with a lumped constant line surge impedance, it was necessary that twice the traveling wave voltage be applied to the equivalent circuit. A discussion of this lumped equivalent circuit may be found in most any treatise on traveling waves and is quite well known.

The arrangement of capacitors and arresters for a grounded neutral generator is shown on figure 1. The applied transient voltage was a 76-kv-crest flat-top wave, which was reduced first by the line type arrester and then by the capacitors and arresters at the generator terminal. The cathode ray oscillograms on figure 1 indicate how the transient voltage is reduced in steps. Starting with the 76-kv flat-top wave, the line type arrester first reduces the crest of the transient to the gap breakdown and *IR* voltage of that arrester, which in turn is further reduced to the low level of 12 kv, by the protective equipment at the machine terminals. The steepness of the front of the impulse is reduced by the small terminal capacitor so that the wave entering the winding rises to its crest in about 12 microseconds.

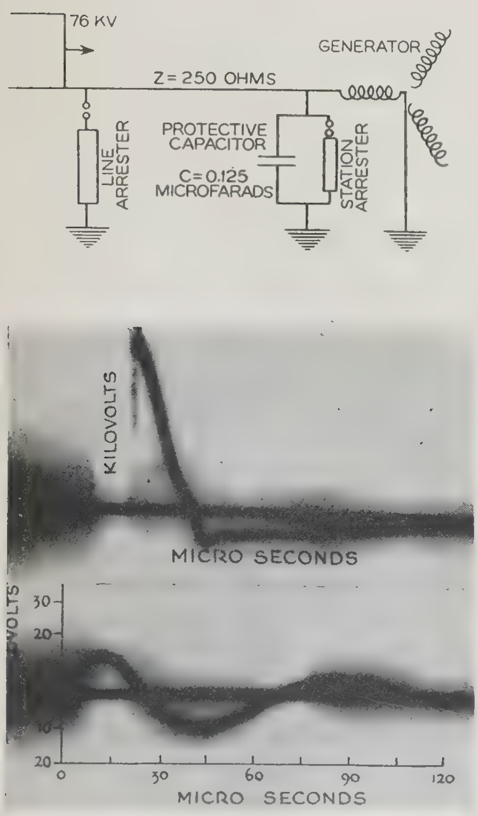


Fig. 1. Oscillograms showing protection obtained for grounded-neutral generator with direct exposure to impulse voltage

Voltage to ground at line arrester

Voltage to ground at generator terminals

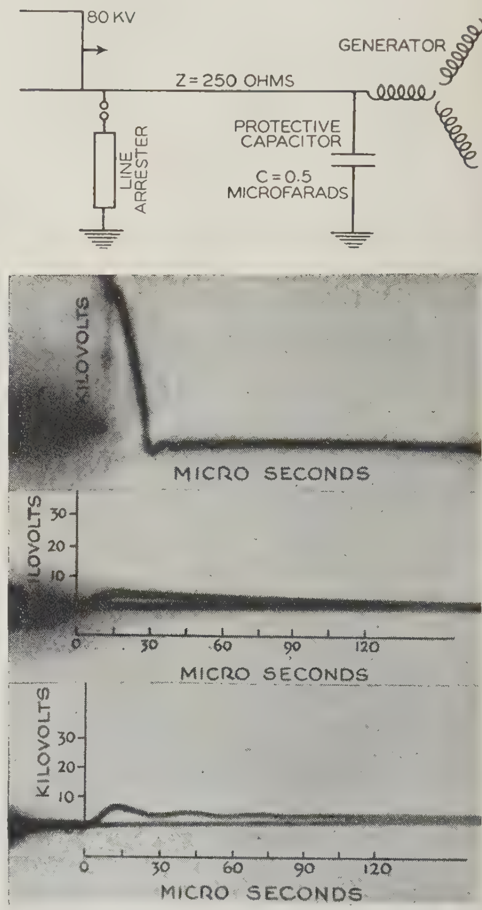


Fig. 2. Oscillograms showing protection obtained for ungrounded-neutral generator with direct exposure to impulse voltage

Voltage to ground at line arrester

Voltage to ground at generator terminals

Voltage to ground at generator neutral

A similar arrangement of protective equipment for an ungrounded neutral generator is shown on figure 2. The applied voltage was an 80-kv flat-top wave which was first reduced by the line type arrester and then by the 0.5 microfarad capacitor at the generator terminals to the low level of 5 kv. It is to be noted from the oscillograms that the capacitor used at the machine terminals was of sufficient size to limit the crest of the wave entering the generator winding and also to limit the reflection at the generator neutral to approximately the same voltage magnitude. The front of the entering wave is approximately 18 microseconds long and the length of one phase of the winding is approximately 4 microseconds. Theoretically the capacitor at the terminals should slope the entering wave so that its front is at least 4 times the winding length if uniform voltage to ground is to be obtained throughout the winding.

These tests were made on only 1 phase of the 3

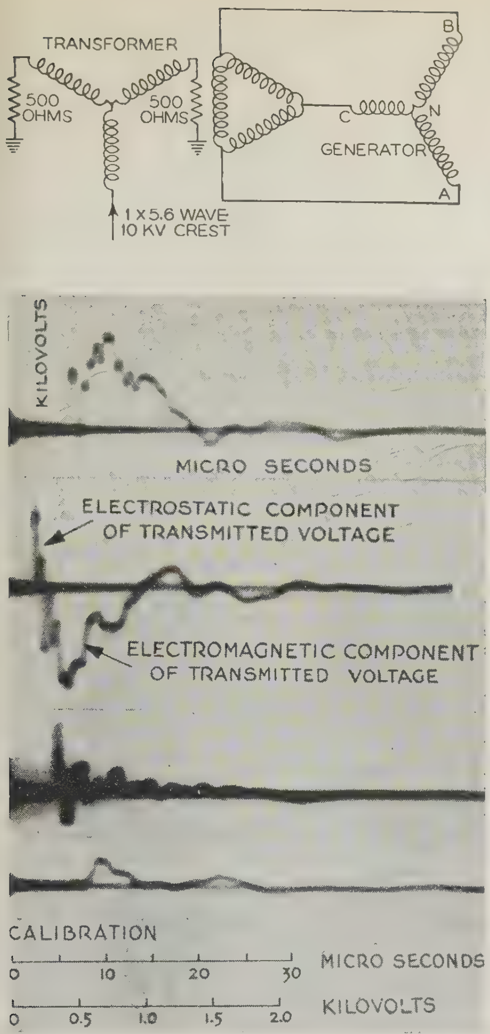


Fig. 3. Oscillograms showing distribution of voltage on generator side of wye-delta transformer resulting from impulse to one phase of the line side of transformer

Voltage to ground at generator terminal *A*

Voltage to ground at generator terminal *B*

Voltage to ground at generator terminal *C*

Voltage to ground at generator neutral *N*

phase winding, the other 2 phases being disconnected at the neutral. Therefore, the reflections at the machine neutral are equivalent to what would have happened if surges of like polarity and magnitude entered all 3 phases simultaneously.

While it is realized that there are certain limitations in simulating distributed circuits by lumped constants in the laboratory, nevertheless it is considered that these test results are actually indicative of the effectiveness of this protective scheme in limiting the transient voltage reaching a rotating machine connected to an exposed overhead circuit. Obviously, for accomplishing the greatest security against direct strokes in practice, the exposed line section between the machine and the line arresters should be effectively shielded by overhead ground wires so that direct strokes will not terminate on the line conductors in this section. Where overhead ground wires are not used, there is an advantage in using a set of line type arresters about 500 feet out from the machine in addition to the line arresters located 2,000 feet out.

Lightning Protection—Machines Connected to Overhead Lines Through Transformers

Rotating machines having transformers between them and the overhead exposed lines require protection from lightning also, as traveling waves may be transmitted both electrostatically and electromagnetically to the rotating machine. The basic theory on the propagation of transient voltages through transformers has been given.[3] Briefly, the impact of a traveling wave on one phase of a wye-delta power transformer is transmitted electromagnetically to the low-voltage delta-connected side as a phase-to-phase voltage. That is, one of the low voltage phases will be raised to a positive potential above ground, the second to an equal negative potential, and the third remains at zero potential. Since the voltages are induced between phases and are of opposite polarity, the transient voltage at the rotating machine neutral remains at substantially zero potential and consequently, the capacitors at the machine terminals need only to be large enough to protect the machine turn insulation. The electrostatic components of the transient voltage appearing on the delta side of the transformer are of the same polarity as the impact voltage, but are of a very short duration and consequently have a low energy content. The lightning protective equipment usually consists of special station type lightning arresters and capacitors on the machine side of the transformers. The effectiveness of this protective equipment is enhanced if lightning arresters are used also on the line side of the power transformer because the magnitudes of the voltages appearing on the machine side of the transformer are directly proportional to the voltages permitted to reach the line side.

Tests on Propagation of Surges Through a Wye-Delta Transformer

The majority of transformers used with generators are connected wye-delta, with the delta on the generator side, and this was the transformer connection chosen for the test. The transformer consisted of 3

Conditions of test:
Circuit as shown on figure 3
Test wave 1 × 5.6-microsecond 10-kv crest positive wave
Transformer turn ratio 5:1
Transformer inductance 0.018 henries
Generator surge impedance 200 ohms

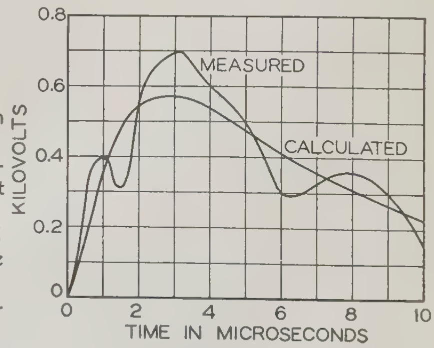


Fig. 4. Measured and calculated electromagnetic component of voltage-to-ground on low voltage side of wye-delta transformer

single phase distribution transformers rated 25 kva, 2,200/1,100/220/110 volts each. Although the kilovolt rating of this bank of transformers was much smaller than that of the generator, it was sufficient for the purpose of these tests.

Cathode ray oscillograms are shown on figure 3 of the measured transient voltages to ground at the

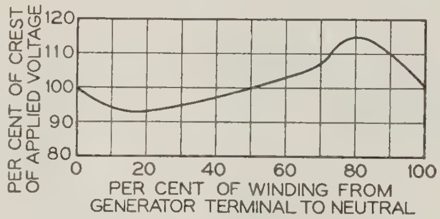
3 generator line terminals and at the neutral of the generator resulting from the application of a 1 x 5.6-microsecond 10-kv-crest positive wave to one phase of the high side of the wye-delta transformer connected to the generator terminals. These oscillograms show the division of voltage as previously described and it is particularly to be noted that the voltage is induced between phases. The neutral voltage measured results from the electrostatic components of the transmitted voltages which are attenuated and elongated as they pass through the winding and which, being of like polarity, do not cancel at the neutral. The transformer neutral was ungrounded for the transmitted voltages shown. Other tests indicated that the same electromagnetic distribution of voltage was obtained with the transformer neutral grounded.

The electromagnetic component of voltage appearing on the generator side of the transformer has been calculated for the conditions of the test using the methods given in the paper listed in reference 3. The calculated and measured voltages are shown on figure 4. There is a reasonably close agreement between the calculated and measured magnitude of the voltage, considering that the oscillatory components of the transmitted wave were neglected in the calculations. The irregularities in the measured wave shape are probably caused by these components.

The tests have shown that the neutral of the generator remains at substantially zero potential during transient voltage disturbances and thus it would be expected that the common ground connection for 3 lightning arresters connected to the generator terminals would also remain at zero potential whether or not the common point was grounded. Tests indicated that there was practically no voltage at the isolated neutral of 3 low voltage arresters located between the generator and transformer when the line side of the transformer was subjected to a 1 x 5.6-microsecond 10-kv crest wave. This suggests that the arresters could be wye connected but ungrounded, or connected between phases when the lightning exposure is only through the transformers between the generators and overhead lines.

Under some conditions there may be a certain distinct advantage in having the arresters isolated from ground. The impulse voltage level which can be maintained by an arrester is directly a function of the maximum permissible dynamic voltage rating of the arrester, which is determined by the maximum operating frequency overvoltage conditions that may exist in the station. The lower the maximum permissible voltage rating, the better the protection obtained. The maximum generated voltage to which an arrester may be subjected when connected from line to ground occurs during a line-to-ground fault on the generator side of the transformer with the generator neutral ungrounded. Thus, if these operating contingencies are considered in applying arresters, then the arresters connected from line to ground must be suitable for the maximum line-to-line voltage. With the arresters connected in wye and the neutral of the arresters isolated from ground, each arrester need only be suitable for the line to neutral voltage and consequently they offer much better protection because of the reduced dynamic voltage rating. Furthermore, it follows logically that the arresters could also be connected directly between phases with similar benefits. An arrester to be correct in its application should be able to withstand the maximum generated voltage and maintain a surge voltage level which is safe for the machine being protected. For those applications where an unusually high rating of arrester would be required to satisfy the system voltage conditions from line to ground, and where the surge voltage level is to be held to a low value, this proposed ungrounding of the neutral of a 3 phase arrester may prove to be useful.

However, this proposed arrester connection has one limitation in that the arrester only maintains the phase-to-phase voltage to a safe value and consequently only indirectly maintains the voltage to ground. Protection probably will not be obtained then if a ground occurs on the generator side of the transformer because the symmetry of the transmitted voltages will be upset.



Tests made with 1.5x 33-microsecond 10-kv crest positive wave

Fig. 6. Envelope of the crests of the line-to-ground voltages through generator winding with lightning arrester in neutral

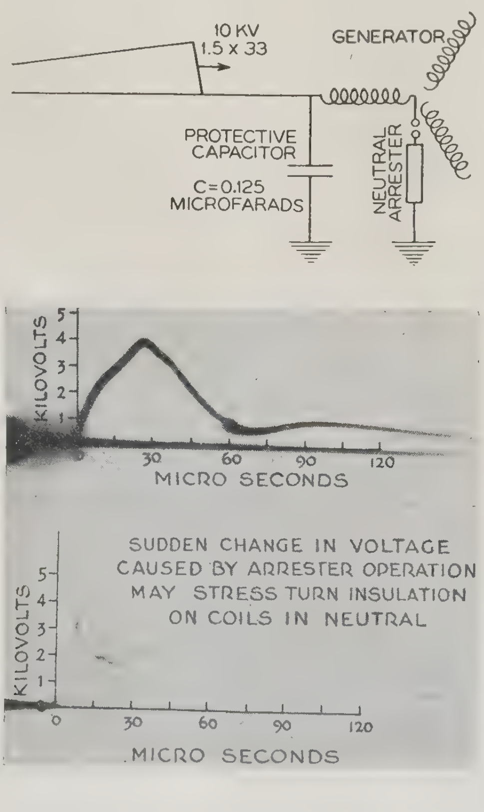


Fig. 5. Oscillograms showing protection obtained for ungrounded-neutral generator with neutral arrester with small line-terminal capacitor and neutral arrester

Voltage to ground at generator terminals

Voltage to ground at generator neutral

The protective capacitors should always be connected from line to ground for their most effective reduction of the transient voltages and this connection can be used in all cases because the voltage rating of a capacitor is not necessarily a limitation on its protective qualities.

Lightning Protection for the Machine Neutral

The question has arisen from time to time as to the merits of locating arresters in machine neutrals to keep the neutral reflected voltages to safe values, as this would permit the use of a more economical size of capacitor at the machine terminals. An arrester, on account of its gap, is normally nonconducting so that until the arrester gap is broken down, the neutral of the machine is in effect open-circuited.

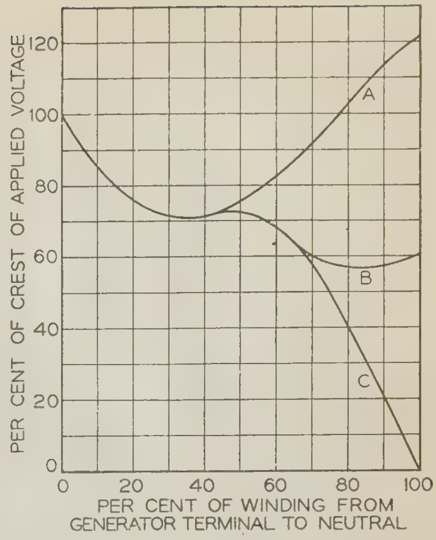


Fig. 8. Envelope of crests of voltages-to-ground through generator winding with various neutral connections

Tests made with 1 x 5.6-microsecond 10-kv crest positive wave

A—Neutral ungrounded

B—Neutral grounded through 200 ohms resistance (winding surge impedance)

C—Neutral solidly grounded

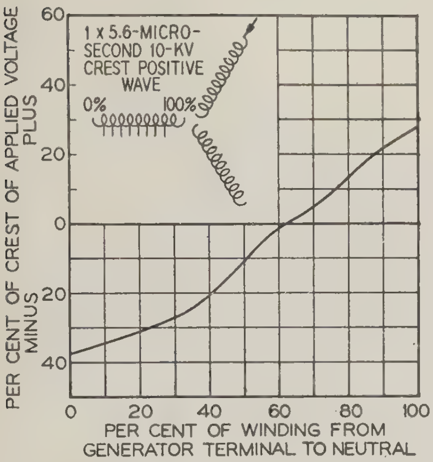


Fig. 7. Envelope of crests of induced voltages-to-ground through phase 2 resulting from applied voltages on phase 1

Thus, a transient reaching the neutral will be reflected positively (reflected wave of same polarity as incoming wave) until the voltage rises to the impulse spark-over voltage of the arrester. That portion of the wave which is reflected positively will travel back into the machine and add to the incoming wave and may produce a higher voltage to ground than that which passed the line terminal protective equipment.

Furthermore, the breakdown of the gap of any neutral arrester produces a sudden drop in voltage which may cause a high stress on the insulation between turns in the armature coils near the neutral.

Tests on Protection for the Machine Neutral

The distribution of voltage to ground through one phase of the generator winding with an arrester at the neutral end was determined by impulsing this phase with a 1.5 x 33-microsecond 10-kv crest positive wave. The envelope of the crests of the measured maximum voltage to ground at the various taps on the winding is shown on figure 6. It is to be noted that the positive reflection which occurs before the neutral arrester functions causes the voltage to ground for a distance back from the machine neutral to exceed the crest of the incoming voltage for the particular wave used in this test. In attempting to draw conclusions from this test, it is recognized that factors such as the wave front and crest of the incoming voltage, length and surge impedance of the machine winding, and the voltage rating of the arrester used, all definitely influence the results obtained. The test wave used had a steeper front than that which would have entered the generator if a small capacitor of the order of a 0.1 microfarad had been used at the terminals. However, as long as the front of the entering wave is less than the length of the generator winding in microseconds, then the voltage to ground in the generator winding will tend to exceed the crest of the entering voltage wave when positive reflections occur at the neutral. The effectiveness of a terminal capacitor in reducing the wave front depends upon the surge impedance of the line and generator winding. The lower oscillogram on figure 1 shows that for a line surge impedance of 250 ohms and a generator surge impedance of 200 ohms, a 0.125 microfarad capacitor sloped off the entering wave to 12 microseconds when the generator neutral was solidly grounded. It is not unusual to have machines with winding lengths in excess of 12 microseconds, so it appears improbable that this rise in voltage attending an arrester operation can be entirely mitigated by the small terminal capacitor on the larger machines.

Furthermore, while the increase in the voltage to ground back from the neutral in this particular case is relatively small, it may be significant. The impulse strength of rotating machine insulation is relatively low when compared with transformer insulation and consequently it is more difficult to obtain adequate protection for a rotating machine. In many applications the lowest impulse voltage level which can be maintained by the terminal protective equipment is of the order of the maximum allowable impulse voltage on the machine, and hence, any protection practice such as the combination of a neutral arrester and small terminal capacitor which may permit an increase in this voltage back in the winding is considered inadvisable.

The sudden drop in voltage when the neutral arrester functions and the voltage wave entering the

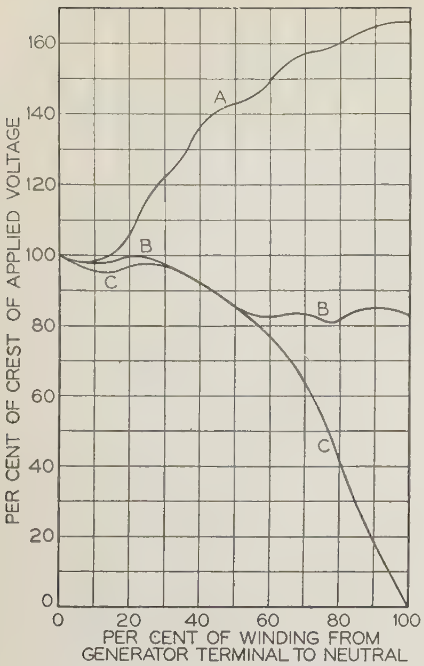


Fig. 9. Envelope of crests of voltages-to-ground through generator winding with various neutral connections

Tests made with 1.5x33-microsecond 10-kv crest positive wave

A—Neutral ungrounded

B—Neutral grounded through 200 ohms resistance (winding surge impedance)

C—Neutral solidly grounded

generator winding are shown by the oscillograms of figure 5. For this test, a capacitor rated 0.125 microfarads and a special low rated arrester comparable with the test voltage and typical in behavior to higher rated arresters were used at the generator terminals and neutral, respectively. The measured voltage from neutral to ground shows a very sudden drop at the crest of the wave when the neutral arrester gap broke down. This arrester gap breakdown in effect applies a steep front wave to the neutral end of the generator winding, and on multiturn windings, may cause high turn-to-turn stresses.

From the results of these tests, it is concluded that because of the possible increase in the line-to-ground voltage in the winding, and even more possible high turn stresses in neutral coils on machines with multiturn windings, the combination of a neutral arrester and small terminal capacitor is an inadvisable item of lightning protective equipment for rotating machine protection. For machines with an ungrounded neutral, a higher degree of protection can be obtained for the machine neutral by the use of a suitable large size capacitor at the machine terminals, as shown on figure 2.

Propagation

The general results of these tests in regard to the propagation of surges through the windings may be summarized as follows:

1. The predominating reaction of the winding to traveling waves was similar to that of a short section of transmission line. The electrical length of the winding was very definitely indicated on the oscillograms. There was a slight rise in voltage at the machine neutral at the instant the wave entered the winding, due to small mutual coupling, but it required a measurable length of time for the major portion of the transient to reach the neutral.

2. The velocity of propagation of the traveling wave through the armature winding was 21,000 miles per second. Assuming the velocity in the end sections of the winding to be of the order of that found in a cable, i. e., 100,000 miles per second, then the velocity in the slot portion of the winding is calculated to be 11,000 miles per second.

3. Coupling, which appeared to be predominantly electromagnetic, was observed between phases and also between adjacent parts of the same phase. The envelope of the crest of the induced voltages to ground measured on the taps on one of the phases of the machine is shown in figure 7. This coupling appeared to have little influence on the protection obtained from the external protective equipment.

4. The traveling waves were found to reflect positively (reflected wave of same polarity as incoming wave) at the machine neutral when the other 2 phases were disconnected. A 22 per cent increase over the voltage entering the machine was found at the neutral with the 1 by 5.6-microsecond and a 66 per cent increase with the 1.5 by 33-microsecond 10-kv-crest positive waves. With the neutral grounded through resistance equal to the measured surge impedance of the winding, the voltage to ground throughout the winding was less than the voltage at the line terminals. This drop in voltage probably resulted from the attenuation of the impulse as it traveled through the winding. With the neutral solidly grounded, distribution of voltage to ground through the winding was such that approximately $^2/_3$ of the entering voltage at the line terminals was noted only $^1/_8$ away from the neutral end of the machine with both test waves. The distribution of voltage through the machine winding with the 1 by 5.6 microsecond wave is shown on figure 8 and for the 1.5 by 33 microsecond wave on figure 9.

5. The attenuation of a chopped wave, or voltage sliver, such as would occur as the result of a front of wave flashover of an insulator was found to be very rapid. A reduction to 20 per cent of its original value in traveling only 10 per cent of the winding was noted.

Surge Impedance

The measured surge impedances of several rotating machines are on record and there is a wide variation in the values given by different investigators. Boehne[1] reported surge impedances varying from 685 to 1,000 ohms on 3 machines tested. Calvert[6] found one machine that had 365 ohms. Further tests on a turbine generator and induction motor have given 200 and 1,600 ohms, respectively. Since there has been such a wide variation in the surge impedance, it is desirable to look for an explanation.

The measured surge impedances which are available were obtained by either 1 of 2 methods, each of which requires a surge generator and a cathode ray oscillograph. One method is to connect a resistance of 400 ohms between the surge generator and the machine being tested and record the open circuit voltage of the surge generator with the machine disconnected and then the voltage at the junction of the 400 ohm resistor and the machine. The machine surge impedance is then obtained from the formula

$$Z = \frac{400\, E_2}{(E_1 - E_2)}$$

Table I—Measured Surge Impedances

Rated Machine Voltage	Machine Rating	Machine Manufacture	Turns per Coil	Measured Surge Impedance per Circuit
6,600	12,500 kva	G.E. Co.	1	200
13,800	25,000 kva	W.E. & M. Co.[6]	3	365
2,200	40 hp	G.E. Co.[1]	5*	685
24,000	15,000 kva	G.E. Co.[1]	5	1,000
6,600	1,400 kva	G.E. Co.[1]	6	800
2,200	60 hp	G.E. Co.	14**	1,600

* Special winding.
** Half back wound coil. All other machine windings had straight wound coils.

where

E_1 = voltage when machine is disconnected
E_2 = voltage when machine is connected

The other method is to record the neutral reflected voltages on one phase of the machine winding with various values of neutral grounding resistances. The value of grounding resistance which reduces the neutral voltage to $^1/_2$ of the reflected or open circuit neutral voltage is considered to be the surge impedance of the machine winding. For this test, the other 2 phases of the machine are disconnected at the neutral.

Test Data on Surge Impedance

The surge impedance of the turbine generator armature winding under test was found by determining what value of neutral grounding resistance would reduce the open circuit neutral voltage to $^1/_2$. The tests indicated that the surge impedance was 200 ohms for both the 1 by 5.6-microsecond and the 1.5 by 33-microsecond 10-kv crest positive waves as shown on figure 10. The merits of this or other methods of testing will not be discussed except to say that the possible error in this case can be at least 10 per cent.

Measured surge impedances per circuit of some other rotating machines are given in table I. The values range from 200 to 1,600 ohms.

Appreciating the fact that only a limited number of test data are available at the present time, and that consequently any general conclusions are hardly in order, still it is of interest to note what factors of machine design apparently influence the surge impedances, for the data in table I indicate certain definite trends.

Keeping in mind that a very approximate expression for the surge impedance is the square root of the quotient obtained by dividing the circuit inductance by the circuit capacity, these trends are as follows:

1. *Number of Turns per Coil.* The inductance of an armature coil varies as the square of the number of turns and, consequently, the

Table II—Protection of Rotating Machines From Lightning

Exposure to Lightning	Transformer Connections	Machine[II] Neutral Connection	Protective Equipment: Capacitance in Microfarads	Protective Equipment: Special[III] Sta. Type Arr.
Direct connection[I]		Grounded	0.1 or more	Yes[IV]
to overhead lines		Ungrounded	0.5 or more	No
Through transformers	YY[V]	Grounded	0.1 or more	Yes
	YY[V]	Ungrounded	0.5 or more	Yes
	Y-Δ, etc.	Grounded	0.1 or more	Yes
	Y-Δ, etc.	Ungrounded	0.1 or more	Yes
Through transformers and direct connection to overhead lines[1]	Y-Y[V], Y-Δ, etc.	Grounded	0.1 or more	Yes
		Ungrounded	0.5 or more	Yes

I. Line type arresters should be located on each exposed feeder at points 500 and 2,000 feet from station or from line of incoming cable.

II. If protective equipment is to do duty for more than one machine, select ungrounded neutral equipment if any machine neutral in group is ungrounded.

III. Lower gap breakdown voltage than on standard station arrester.

IV. Arresters may be omitted if capacitor exceeds 0.5 microfarads.

V. Both neutrals grounded.

Note—Feeder regulator and reactors. Where machine is connected to exposed line through feeder regulator or reactors, use same protection as required for machine directly connected to exposed lines, except in every case the capacitor should be paralleled with a station arrester.

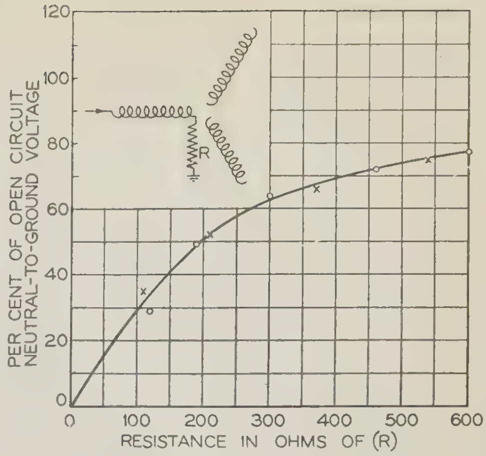


Fig. 10. Surge impedance determined from neutral reflected voltages

Circles—1 x 5.6-microsecond 10-kv positive wave

Crosses—1.5 x 33-microsecond 10-kv positive wave

surge impedance should directly increase with the number of turns, other factors being equal. The data in table I are arranged in the order of the number of turns in the coils of the machine and it is to be noted that the higher the number of turns, the higher the measured surge impedance.

2. *Voltage Rating.* An increase in voltage rating requires increased insulation and, consequently, larger slots, which, in general, tend to increase the inductance and decrease the capacitance and, consequently, tend to increase the surge impedance.

3. *Kilovolt-ampere Rating.* If it is assumed that increased rating means increased conductor size, which, in turn, requires a larger slot, then both the inductance and the capacity may be increased so that the net result may either be an increase or a decrease in the surge impedance. Much will depend upon the individual design.

4. *Number of Circuits per Phase.* The surge impedance per phase multiple circuit winding is approximately the surge impedance of one of the circuits divided by the number of circuits.

Conclusions

Based upon the test data presented in this paper the following conclusions have been reached:

Lightning Protection

1. The voltage stresses in a-c rotating machines connected to exposed overhead lines may be limited by line type arresters located approximately 2,000 feet from the station on each incoming line and protective capacitors and suitable station arresters (when required) at the machine terminals.

2. The use of a lightning arrester in the machine neutral, to limit neutral reflected voltage, is considered inadvisable. Neutral reflections can be limited more satisfactorily by the use of the proper size of protective capacitor at the machine terminals.

3. A-c rotating machines connected to exposed overhead lines through wye-delta connected transformers do not require large size terminal capacitors to limit the neutral reflections because the transient voltages that appear on the machine side of the transformer cancel at the rotating machine neutral.

Propagation

1. The grading of insulation in rotating machine armature windings has been frequently discussed in recent years. Several 33 kv generators have been built and are in service in Europe today with the line end third of the winding insulated for 33 kv, the middle third for 22 kv, and the neutral end third for 11 kv. Some of these machines have stator windings which are circular and arranged concentrically, and others have the multiturn rectangular conductor with rounded corners and with 2 coil sides per slot. A few conclusions on the response of this latter type of winding to transient voltages based upon the results of these tests on the turbine generator winding will be given here.

2. Obviously, a machine with graded insulation should be wye-connected. The neutral of the machine should be grounded to prevent dangerous neutral reflections. However, the solidly grounded

neutral does not insure that the insulation back from the neutral will not be overstressed for in the tests approximately $^2/_3$ of the magnitude of the entering wave was measured at a point only $^1/_3$ from the solidly grounded neutral. These tests indicated that both arresters and capacitors at the machine terminals would be needed to protect the insulation to ground.

3. Furthermore, the data on surge impedances of armature windings indicate that this impedance varies directly with the number of turns per coil. A transient in passing from a lower to a higher surge impedance reflects positively and consequently the winding of the machine with graded insulation should have the higher number of turns per coil in the higher insulated sections so that when the surge passes from a higher to a lower insulated section there will be a corresponding decrease rather than a rise in the transient voltage.

Surge Impedance

1. The surge impedance of a machine armature winding varies directly with the number of turns per coil, increases somewhat as the voltage rating increases and may be either increased or decreased by an increase in the kilovoltampere rating.

2. The surge impedance per phase is approximately the surge impedance per circuit divided by the number of circuits.

Suggestions for Lightning Protective Equipmfnt for A-C Rotating Machines

General rules governing the selection of lightning protective equipment are given in table II.

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Induction Motor Resistance Ring Width

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The effect which the width of resistance rings has on the secondary resistance of squirrel cage induction motors has been subjected to a mathematical analysis. It is found that the width, in a radial direction, of these rings which connect the conductors of a squirrel cage rotor, need never exceed the pole pitch, and probably half of that value is sufficient. Methods for determining the current distribution in the resistance ring, and for determining the the effective width and resistance are demonstrated.

There are 3 periods through which most engineering design methods pass: first, that period when only general relations and laws are known, and engineering design is simply cut and try with a few general laws to serve as guides; second, the period when the theory has been developed, and calculation methods, sometimes long and cumbersome, and sometimes very much abbreviated, are in use; and third, the period in which design methods are being revised, and put into the most usable shape, and a more thorough knowledge is obtained as to the necessary short cuts, or refinements, as the case may be, for each particular class of machine.

A paper recommended for publication by the A.I.E.E. committee on electrical machinery. Manuscript received Oct. 1, 1935; released for publication Oct. 26, 1935.

Induction motor design has passed into the third stage, and this paper presents another refinement in the calculation of secondary resistance. Particular attention is given to the width in a radial direction of the resistance rings which connect the ends of the rotor bars in a squirrel cage motor. It is shown that it is not correct, for a wide resistance ring, to base calculations upon the average diameter of the ring, and that it is also not correct to assume that the ring is all concentrated at the conduction circle.

Secondary Resistance

A method of calculating the effective secondary resistance of a squirrel cage induction motor has long been used, and a complete derivation is given in appendix I. The writer would prefer to give credit for this derivation, but it has passed through many hands and the source is unknown to him.

The derivation is based upon the ideal case of a cylindrical sheet or drum of copper replacing the conductors, and this sheet joining a small connecting ring at each end. Assuming sinusoidal current distribution in the primary, the current density in the sheet is in turn sinusoidal. The current in the ring at any point can be obtained by integrating. The density in the ring also turns out to be distributed

sinusoidally. Knowing the current densities and areas of the ideal case, the specific losses and total losses for the ideal case can be calculated. From the losses and equivalent secondary current, the equivalent secondary resistance for the ideal case can be calculated. It is then a simple matter of substitution to replace the ideal cage by the actual squirrel cage.

It is the purpose of this paper to point out 2 things. One is a plain case of common misinterpretation, and the other is a case of an assumption which is not good under certain conditions.

The equation for secondary resistance as derived in appendix I is as follows:

$$r_2 = [(CKw)^2\,\rho\phi]\left\{\frac{\sqrt{W^2 + SK^2}}{S_c S_s\ \%\text{Cond}} + \frac{0.637\ D_r}{S_r p^2\ \%\text{Cond}}\right\}$$

where

CKw = total effective series conductors per phase
ϕ = number of phases (taken as 2 for single phase)
ρ = conductivity of copper (0.694×10^{-6}) ohms per inch cube at 25 degrees centigrade)
W = axial width of rotor in inches
SK = skew of rotor in inches
S_c = area of rotor conductor in square inches
S_s = number of rotor conductors
%Cond = per cent conductivity of material times 100, in terms of copper
S_r = area of resistance ring in square inches
p = number of poles
D_r = diameter at which conductors enter the ring

It is this diameter D_r which is so often misinterpreted. D_r is taken to be the mean diameter of the resistance ring, and for most induction motors above 5 horsepower, this is a perfectly justified assumption for it actually coincides with the diameter as taken above.

However, for a wide resistance ring, the average diameter is not correct, for that would mean on a multipolar machine, that a wide thin ring would have less resistance than a square ring of the same cross section due to its average diameter being smaller. This becomes quite obviously wrong, if carried to an extreme case. For instance, consider a 32 pole machine with a rotor 10 inches in diameter with small conductors. The pole pitch would be approximately one inch. Suppose a resistance ring reaching to a shaft of 2 inches diameter is used. Very little of the current will travel the 8 inch path to the bottom of the ring and back when going only one inch from pole to pole.

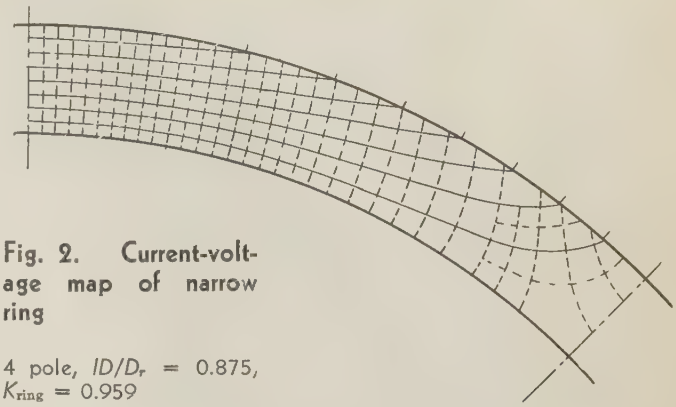


Fig. 2. Current-voltage map of narrow ring

4 pole, ID/D_r = 0.875, K_{ring} = 0.959

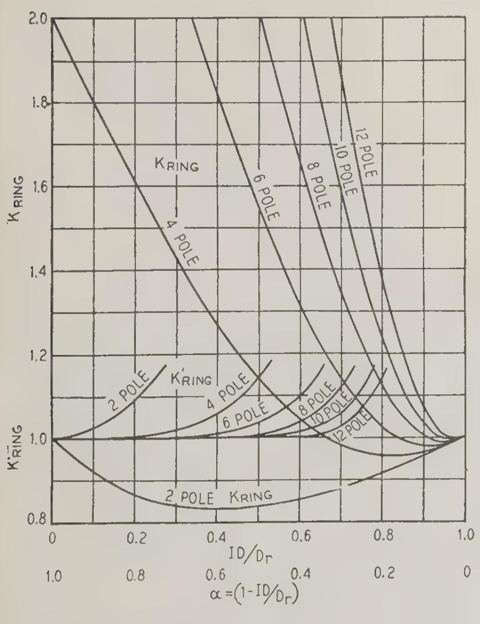


Fig. 1. Effect of wide resistance ring on secondary resistance of squirrel cage rotors

Effect of Wide Resistance Ring

This brings up the second point that in the case of a wide resistance ring, it is not correct to assume the ring all concentrated at the conductor circle. The current will distribute itself in the ring as an electric field, and must be handled as a field, not as a conductor or wire circuit.

The writer has determined the field maps for different numbers of poles and different widths of rings, and figure 1 gives the correction factor K_{ring} which should be applied to the second term of the resistance equation. Thus:

$$r_2 = [(CKw)^2\,\rho\phi]\left\{\frac{\sqrt{W^2 + SK^2}}{S_c\ S_s\ \%\text{Cond}} + \frac{0.637\ D_r}{S_r\ p^2\ \%\text{Cond}}\,K_{ring}\right\}$$

It will be noted that only for 2 pole and a very small proportion of other cases, does the old assumption of the mean ring diameter tend to give a correct result. In all other cases, the old method gives a lower resistance than the ring actually has.

Figure 2 shows how the narrow ring approximates the assumption of sinusoidal distribution along the ring and uniform distribution across its section and figure 3 shows how far the assumption of uniform distribution in the ring section is from the true picture, in the case of a wide ring.

Figure 1 also shows another interesting relation. By letting

$$K'_{ring} = \frac{K_{ring}}{p/2\,(1 - ID/D_r)}$$

the ring resistance becomes proportional to

$$\frac{D_r\,\frac{p}{2}\,(1 - ID/D_r)}{p^2\,W_r}\,K'_{ring} \text{ or to } \frac{K'_{ring}}{p}$$

The value K'_{ring} is also plotted on figure 1, showing that as the ring becomes very wide K'_{ring} approaches a constant unity. This means that the resistance has reached its lowest value and no further reduction in ring resistance will be obtained by widening the ring. In practice, moreover, it would probably not be worth while to make the ring as wide as the maximum point shown by figure 1, because the width of the ring could be decreased a considerable amount with only a few per cent increase in ring resistance. Also, on multipolar machines, the ring resistance is usually not even half the bar resistance so that the total percentage increase in rotor resistance would be very small.

For machines of a large number of poles, the curves of figure 1 have been replotted in figure 4, against the ratio W_r/λ_{pr} instead of ID/D_r.
where

W_r = width of ring
λ_{pr} = pole pitch at D_r

The curves of K'_{ring} in figure 4, bring out the fact that the width of ring need never exceed the pole pitch, and probably half that value is sufficient.

The above relations have all been derived on the assumption of the conductor circle at the periphery of the ring. Of course, this is not quite the case in commercial designs. However, if the following points are kept in mind, the assumption will seem more justified. The width and cross sectional area are taken as the actual value. Then the only error lies in applying the correction factor to the whole ring which is correct for only part of it. In applying the correction factor, K_{ring} is used for the ratio of ID/D_r where D_r is the diameter of the conductor circle and the outer periphery. However, if the ring is wide, the outer portion is small and a small error in K_{ring} for that part makes little difference. If the ring is narrow so that the inner and outer parts are alike, the correction factor is nearly unity, and nearly the same for each, so that in any case, the error is very small. In the case of very deep bars, many poles, and a wide ring, it may possibly be desirable to calculate each part of the ring separately and determine their resistance when in parallel.

Method of Obtaining Current Distribution Maps

There are 2 methods of obtaining the curves of figure 1. One is by direct calculation of the distribution and losses, and the other by graphically sketching the maps. Usually calculation of field distributions is rather involved mathematically, and it was first attempted to obtain the maps by the usual graphical method commonly employed in mapping magnetic fields. That is, a cut and try method of free hand sketching is applied until the "tubes" of equal current cut the equipotential surfaces at right angles, and form the well known "curvilinear squares."

In this case, as in many others, it was found desirable to determine as many boundary conditions as possible before starting the free hand part of the work. It was easily possible to determine the terminals of the equal current tubes at the conductor circle, since sinusoidal distribution had been assumed. Appendix II gives the method of calculating these points. A number of maps similar to figures 2 and 3 were made, and interpreted as shown in appendix II, to obtain curves similar to figure 1.

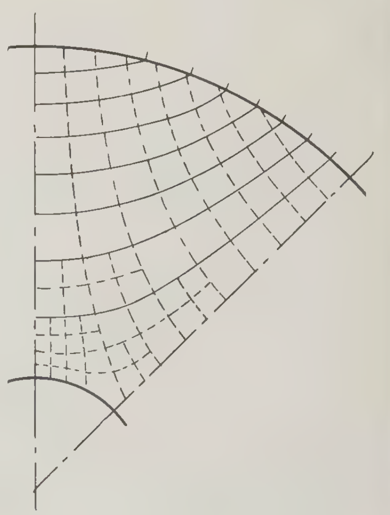
However, at this point, it was found that equations for a field similar to the one under consideration were given in a paper on core losses by Alger and Eksergian in 1920 (see reference 1 at end of paper). These equations had originally been derived by Rudenberg, and while intended for use in calculating core loss, apply with some adjustment to the resistance ring. The equations were still considered too cumbersome to use in calculating the whole field, but were easily adapted to determine the points where the equal current tubes cross the radius midway between poles. This method is shown in appendix III.

With both ends of the current tubes determined, the maps become much more accurate, and quite a number were plotted. Figures 2 and 3, however, show that while for wide rings the maps are definite and accurate, for narrow rings, any error in estimating the width, and length of the squares, results in a directly proportional error in K_{ring}. Even in this case, it is easily possible to obtain maps of 5 per cent accuracy, but this accuracy, while perhaps sufficient for calculating the correction factor, was not very satisfactory in determining the exact shape of the curves as they approach unity.

Still further investigation of Mr. Rudenberg's equations was made and it was finally found possible to derive the exact equation for the correction factor

Fig. 3. Current-voltage map of wide ring

4 pole, ID/D_r = 0.250, K_{ring} = 1.51



K_{ring} and eliminate the necessity of constructing the field maps. The equation is surprisingly simple, and very similar in form to that presented by Alger and Eksergian as a correction for eddy current core loss.

$$K_{ring} = \frac{p}{2}(1 - ID/D_r)\frac{\left[1 + \left(\dfrac{ID}{D_r}\right)^p\right]}{\left[1 - \left(\dfrac{ID}{D_r}\right)^p\right]}$$

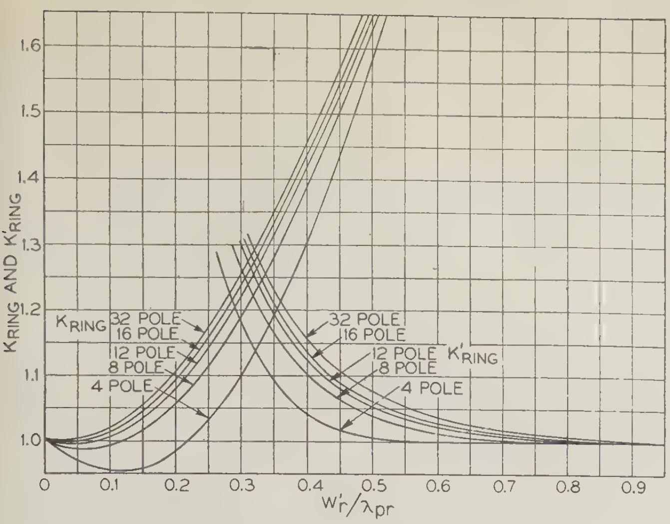


Fig. 4. K_{ring} and K'_{ring} as a function of ring width and pole pitch

and

$$K'_{ring} = \frac{K_{ring}}{p/2\,(1 - ID/D_r)} = \frac{\left[1 + \left(\dfrac{ID}{D_r}\right)^p\right]}{\left[1 - \left(\dfrac{ID}{D_r}\right)^p\right]}$$

The derivation of these equations is given in appendix III. The curves of figures 1 and 4 were calculated by them.

Appendix I—Equivalent Resistance of Squirrel Cage Rotor

The equivalent resistance of a squirrel cage rotor may be found as follows:

Assume the rotor bars to be replaced by a conducting sheet of metal of uniform thickness with the current flowing along it in straight lines parallel to the rotor axis. Assume the current to be distributed sinusoidally. Let

W = length of bar = length of sheet
S_c = cross sectional area of rotor bars
t = thickness of assumed sheet
S_s = number of rotor bars
ρ_b = resistivity of bar material
S_r = cross sectional area of end ring
ρ_r = resistivity of end ring material
p = number of poles
J = current density
J_m = maximum current density in sheet

Let the origin be midway between poles. Then

$$J = J_m \cos \frac{\pi}{\lambda_p} x$$

where

λ_p = pole pitch

Loss in Bars

The resistance of a strip of the sheet dx wide

$$R = \frac{\rho_b W}{t\,dx}$$

The current in such a strip

$$I = (J_m \cos \frac{\pi}{\lambda_p} x\, t\, dx)^2$$

The loss in such a strip,

$$\text{Loss} = \frac{\rho_b W}{t\,dx}\left(J_m \cos \frac{\pi}{\lambda_p} x\, t\, dx\right)^2 = \rho_b W J_m^2\, t \cos^2 \frac{\pi}{\lambda_p} x\, dx$$

The loss in the sheet equivalent to the loss in the bars

$$\text{Loss} = p\left[\rho_b\, W\, J_m^2\, t \int_0^{\lambda_p} \cos^2 \frac{\pi}{\lambda_p} x\, dx\right]$$

$$\text{Loss} = {}^1/_2\, p\, \rho_b\, W\, J_m^2\, t\, \lambda_p$$

Loss in the End Rings

The current at a point x

$$I = t \int_0^x J_m \cos \frac{\pi}{\lambda_p} x\, dx = t\, J_m \frac{\lambda_p}{\pi} \sin \frac{\pi}{\lambda_p} x$$

Resistance of length dx

$$R = \frac{\rho_r\, dx}{S_r}$$

Loss in length dx

$$\text{Loss} = \frac{\rho_r\, dx}{S_r}\left[t\, J_m \frac{\lambda_p}{\pi} \sin \frac{\pi}{\lambda_p} x\right]^2$$

$$\text{Loss} = \frac{\rho_r}{S_r} t^2\, J_m^2 \frac{\lambda_p^2}{\pi^2} \sin^2 \frac{\pi}{\lambda_p} x\, dx$$

Total loss in both rings

$$\text{Loss} = 2\, p \frac{\rho_r}{S_r} t^2\, J_m^2 \frac{\lambda_p^2}{\pi^2} \int_0^{\lambda_p} \sin^2 \frac{\pi}{\lambda_p} x\, dx$$

$$\text{Loss} = \frac{p\, \rho_r\, t^2\, J_m^2\, \lambda_p^2}{S_r\, \pi^2} \lambda_p$$

Total Loss in Rotor Cage

$$\text{Loss} = \frac{J_m^2\, t^2\, \lambda_p^2}{\pi^2}\, p\left[\frac{\rho_b\, W\, \pi^2}{2\, t\, \lambda_p} + \frac{\rho_r\, \lambda_p}{S_r}\right]$$

Total Current Around Each Pole

$$I = t\, J_m \int_0^{\lambda_p/2} \cos \frac{\pi}{\lambda_p} x\, dx = t\, J_m \frac{\lambda_p}{\pi}$$

Since this flows through one turn, it must be the magnetomotive force of the rotor and must equal the magnetomotive force of that component of the primary current due to load. Let

I_2 = secondary or rotor current referred to the primary

Then the magnetomotive force of the primary load current is

$$\frac{\sqrt{2}\, I_2\, CKw}{\pi\, p} \phi$$

If the primary and secondary magnetomotive forces are equated

$$\frac{\sqrt{2}\, I_2\, CKw\, \phi}{\pi\, p} = t\, J_m \frac{\lambda_p}{\pi}$$

Where

CKw = total effective series conductors per phase in the primary
I_2 = secondary or rotor current referred to the primary
ϕ = number of phases

Substituting the above expression in the loss equation,

$$\text{Total loss} = \left[\frac{\sqrt{2}\, CKw\, I_2\phi}{\pi\, p}\right]^2 p \left[\frac{\rho_b\, W\, \pi^2}{2\, t\, \lambda_p} + \frac{\rho_r\, \lambda_p}{S_r}\right]$$

However, the equivalent resistance per phase referred to the primary is r_2, where

$$r_2 = \frac{\text{total loss}}{\phi\, I_2^2}$$

Therefore,

$$r_2 = (CKw)^2 \frac{2\,\phi}{\pi^2}\left[\frac{\rho_b\, W\, \pi^2}{2\, t\, \lambda_p} + \frac{\rho_r\, \lambda_p}{S_r}\right]$$

$$r_2 = (CKw)^2\, \phi \left[\frac{\rho_b\, W}{p\, t\, \lambda_p} + \frac{2\, \rho_r\, \lambda_p}{\pi^2\, p\, S_r}\right]$$

But $t\, \lambda_p\, p = S_c\, S_s$.

Also let λ_p in the second term equal $\frac{D_r\, \pi}{p}$ where

D_r = the diameter at which the conductors enter the ring.

Therefore,

$$r_2 = (CKw)^2\, \phi \left[\frac{\rho_b\, W}{S_c\, S_s} + \frac{2\, \rho_r\, D_r}{\pi\, p^2\, S_r}\right]$$

Let this equation be rewritten in terms of the conductivity in relation to copper, and also take the true length of conductor.

$$r_2 = [(CKw)^2\, \phi\rho] \left\{\frac{\sqrt{W^2 + SK^2}}{S_c\, S_s\, \%\text{Cond}} + \frac{0.637\, D_r}{S_r\, p^2\, \%\text{Cond}}\right\}$$

where

ρ = resistivity of copper in ohms per inch cube
SK = skew in inches
%Cond = per cent conductivity of bar and ring materials respectively in terms of copper

Appendix II—Boundaries and Interpretation of Current-Voltage Maps

Determination of Boundaries and Interpretation of Current-Voltage Maps of Wide Resistance Rings

As in appendix I, let a conductor sheet carrying sinusoidally distributed current be assumed. Let it be assumed that this sheet joins the resistance ring at its outer edge. In order to aid the sketching of a current-voltage map, let the current entering the ring be divided into equal parts.

$$J = J_m \sin \frac{\pi x}{\lambda_p}$$

where

J = current density in ring at its outer edge
J_m = maximum current density in ring at outer edge
x = distance along the periphery of the ring from a point midway between poles
λ_p = pole pitch
The total current

$$I = J_m\, t \int_0^{\lambda_p/2} \sin \frac{\pi\, x}{\lambda_p}\, dx = J_m\, t\, \frac{\lambda_p}{\pi} \left| -\cos \frac{\pi x}{\lambda_p} \right|_0^{\lambda_p/2}$$

$$I = J_m\, t\, \frac{\lambda_p}{\pi}$$

where

I = total current around one pole
t = thickness of resistance ring

Let

θ = distance along ring in electrical degrees

$$\theta = \frac{\pi}{\lambda_p}\, x$$

$$d\theta = \frac{\pi}{\lambda_p}\, dx$$

$$J = J_m \sin \theta$$

$$I = J_m\, t\, \frac{\lambda_p}{\pi} \int \sin \theta\, dx$$

Let

ψ = any fraction of total current

$\psi = n\, I$

$$\psi = J_m\, t\, \frac{\lambda_p}{\pi} \int_{\theta_1}^{\theta_2} \sin \theta\, d\theta = J_m\, t\, \frac{\lambda_p}{\pi} (\cos \theta_1 - \cos \theta_2)$$

But

$$\Psi = n\, I \text{ and } I = J_m\, t\, \frac{\lambda_p}{\pi}$$

Therefore,

$$n = (\cos \theta_1 - \cos \theta_2)$$

If it is desired, for example, to divide the current into 8 equal parts, $n = 0.125$, $\theta_1 = 0$ and the equation above can be solved for θ_2. $0.125 = (1 - \cos \theta_2)$ and $\cos \theta_2 = 0.875$; thus the first part of the current enters the ring between 0 and 28 degrees 57 minutes. For the second part $n = 0.25$, $\theta_1 = 0$, and θ_2 becomes 41 degrees 35 minutes.

Interpretation of Current-Voltage Maps

With the boundaries of the equal current tubes determined at the periphery of the ring, the current-voltage map may be sketched by the usual method of free hand flux plotting. The total current, has been shown to be

$$I = J_m\, t\, \frac{\lambda_p}{\pi}$$

The current per tube is then

$$\frac{J_m\, t\, \lambda_p}{t_u\, \pi}$$

where tu = number of tubes
The resistance of each square of the map

$$R = \frac{\rho_r \text{ length of square}}{t \text{ width of square}}$$

But the principle of construction of the map is that the length and width of each square shall be equal. Therefore

$$R = \rho_r/t$$

where

ρ_r = resistivity of the ring material

Since the current through each square of the map is the same, and each square has the same resistance, the total loss in both rings of the rotor is

$$\text{Loss} = \left[\frac{J_m\, t\, \lambda_p}{tu\, \pi}\right]^2 \frac{\rho_r}{t}\, squ\ 4\, p$$

where

squ = number of squares per half pole

In appendix I, this loss has been shown to be

$$\text{Loss} = \frac{p\,\rho_r\,t^2\,J_m^2\,\lambda_p^2}{S_r\,\pi^2}\,\lambda p$$

Rewriting the equation derived from the current map into the same form,

$$\text{Loss} = \frac{p\,\rho_r\,t^2\,J_m^2\,\lambda_p^2}{S_r\,\pi^2}\,\lambda_p\left(\frac{S_r\,squ\,4}{tu^2\,t\,\lambda_p}\right)$$

where $S_r = W_r\,t$ = cross section of ring

$$\text{Loss} = \frac{p\,\rho_r\,t^2\,J_m^2\,\lambda_p^2}{Sr\,\pi^2}\,\lambda_p\left(\frac{4\,squ\,W_r}{tu^2\,\lambda_p}\right)$$

Since this loss differs from that found by appendix I, it is necessary, therefore, to correct that part of the resistance equation due to the ring, by the term in parenthesis in the equation above. Let

$$K_{ring} = \frac{4\,squ\,W_r}{tu^2\,\lambda_p}$$

Writing this expression in terms of the diameter at the conductor circle,

$$K_{ring} = \frac{4\,squ\,W_r\,p}{tu^2\,D_r\,\pi}$$

Then,

$$r_2 = [(CKw)^2\,\rho\,\phi]\left\{\frac{\sqrt{W^2 + SK^2}}{S_s\,S_c\,\%\text{Cond}} + \frac{0.637\,D_r}{D_r\,p^2\,\%\text{Cond}}\,K_{ring}\right\}$$

Appendix III—Boundary Conditions of Equal Current Tubes

A. Determination of Boundary Conditions of Equal Current Tubes at Pole Center Line

Reference 1 at the end of this paper gives the following expressions for the flux density in an annular core:

$$B_r = \frac{P\Phi}{2RL}(AR^P - BR^{-P})\cos P\theta = \text{radial flux density in kilolines per square inch}$$

$$B_\theta = \frac{P\Phi}{2RL}(AR^P + BR^{-P})\sin P\theta = \text{tangential flux density}$$

$$A = \frac{a^{2P}\,R_a^{-P}}{a^{2P} - 1} \text{ and } B = \frac{R_a^P}{a^{2P} - 1}$$

where (see figure 5):

P = number of pairs of poles
θ = angular displacement of any point in the core from the center line between poles in mechanical degrees
R = radius to any point in core
R_a = radius of core nearest air gap
R_i = radius of core furthest from air gap
a = R_a/R_i (a is greater than unity)
Φ = total flux per pole
L = net core length

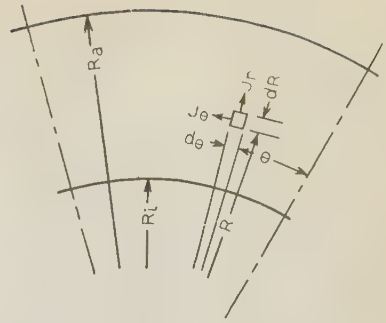
(For the purpose of simplicity, P = pairs of poles will be used in appendix III, whereas all other parts of this paper use p = number of poles.)

For the purpose of analyzing the current map and losses in a wide resistance ring, these equations will be rewritten in terms of the current. The conductor circle will be assumed to be at the periphery of the ring.

$$J_r = \frac{PI}{Rt}(AR^P - BR^{-P})\cos P\theta$$

$$J_\theta = \frac{PI}{Rt}(AR^P + BR^{-P})\sin P\theta$$

Fig. 5. Section of ring, with designations used in analysis of Appendix III



$$A = \frac{1}{R_a^P\,(1 - c^{2P})} \text{ and } B = \frac{c^{2P}R_a^P}{(1 - c^{2P})}$$

where

I = total current around each pole (This corresponds to 1/2 the flux as used by Alger)
t = thickness of the resistance ring
c = $1/a = R_i/R_a = ID/D_r$
D_r = outside diameter of ring
ID = inside diameter of ring

$$J_r = \frac{PI}{t(1 - c^{2P})}\left\{\frac{R^{P-1}}{R_a^P} - c^{2P}\,R_a^P\,R^{-P-1}\right\}\cos P\theta$$

$$J_\theta = \frac{P\,I}{t(1 - c^{2P})}\left\{\frac{R^{P-1}}{R_a^P} + c^{2P}\,R_a^P\,R^{-P-1}\right\}\sin P\theta$$

Boundaries of Equal Current Tubes

To determine the ends of the equal current tubes, the special case of the radius at the center of the pole will be taken. Then

$\theta = \pi/2P$, $\cos P\,\theta = 0$,

$\sin P\theta = 1$, and $J_r = 0$

$$J_\theta = \frac{P\,I}{t(1 - c^{2P})}\left\{\frac{R^{P-1}}{R_a^P} + c^{2P}\,R_a^P\,R^{-P-1}\right\}$$

The current crossing this center line between any 2 radii

$$i = \frac{P\,I}{t(1 - c^{2P})}\int\left\{\frac{R^{P-1}}{R_a^P} + c^{2P}\,R_a^P\,R^{-P-1}\right\}t\,dR$$

$$i = \frac{P\,I}{1 - c^{2P}}\left\{\frac{R^P}{R_a^P\,P} - \frac{c^{2P}\,R_a^P\,R^{-P}}{P}\right\}$$

Let

$r = R/R_a$

$$i = \frac{I}{1 - c^{2P}}\left\{r^P - \frac{c^{2P}}{r^P}\right\}$$

To divide the current into any fraction of the total, starting at the inside of the ring

n = fraction of current

$$n = \frac{\left|r^P - c^{2P}r^{-P}\right|_c^r}{\left|r^P - c^{2P}r^{-P}\right|_c^1}$$

$$n = \frac{r^P - c^{2P}r^{-P}}{1 - c^{2P}}$$

$$r^{2P} - n(1 - c^{2P})r^P - c^{2P} = 0$$

$$r^P = \frac{n(1 - c^{2P}) + \sqrt{n^2(1 - c^{2P})^2 + 4\,c^{2P}}}{2}$$

$$r = \left\{\frac{n}{2}(1 - c^{2P})\left[1 + \sqrt{1 + \left[\frac{2\,c^P}{n(1 - c^{2P})}\right]^2}\right]\right\}^{1/P}$$

where

r = radius including any fraction of current
n = any fraction of current
c = ratio of inside diameter of ring to outside diameter
P = pairs of poles

B. Correction Factor for Wide Rings

The equations for radial and tangential current density in the resistance ring have been given above. The losses caused by these components of the current can now be calculated. Since the resistivity does not vary with current, the total loss will be the sum of the losses of each component.

Loss Due to Tangential Current

Area of incremental portion $= t\,dR$

Length of incremental portion $= R\,d\theta$

$$\text{Resistance} = \frac{\rho\,R\,d\theta}{t\,dR}$$

where

ρ = resistivity of ring material

Current $= J_\theta\,t\,dR$

$$\text{Loss} = (J_\theta\,t\,dR)^2\,\frac{\rho\,R\,d\theta}{t\,dR}$$

$$\text{Loss} = \rho\,R\,t\,J_\theta^2\,d\theta\,dR$$

Loss in both rings

$$W_\theta = 8\,P\,\rho\,t\int\int_{R_i,\,0}^{R_a,\,\pi/2P} R\,J_\theta^2\,d\theta\,dR$$

In the same manner, it can be shown that the loss due to the radial component of the current is,

$$W_r = 8\,P\,\rho\,t\int\int_{R_i,\,0}^{R_a,\,\pi/2P} R\,J_r^2\,d\theta\,dR$$

or the total loss,

$$W = 8\,P\,\rho\,t\int\int_{R_i,\,0}^{R_a,\,\pi/2P}(J_r^2 + J_\theta^2)\,R\,dR\,d\theta$$

but

$$J_\theta^2 = \left[\frac{P\,I}{t(1 - c^{2P})}\right]^2\left[\frac{R^{P-1}}{R_a^P} + c^{2P}\,R_a^P\,R^{-P-1}\right]^2\sin^2 P\theta$$

$$J_r^2 = \left[\frac{P\,I}{t(1 - c^{2P})}\right]^2\left[\frac{R^{P-1}}{R_a^P} - c^{2P}\,R_a^P\,R^{-P-1}\right]^2\cos^2 P\theta$$

$$J_\theta^2 + J_r^2 = \left[\frac{P\,I}{t(1 - c^{2P})}\right]^2\left[\left(\frac{R^{P-1}}{R_a^P}\right)^2 + (c^{2P}\,R_a^P\,R^{-P-1})^2\right]^2 + \left[\frac{P\,I}{t(1 - c^{2P})}\right]^2[2\,c^{2P}\,R^{-2}]\,(\sin^2 P\,\theta - \cos^2 P\,\theta)$$

It can be shown that this second term will integrate to zero, and it will be dropped at this point. Therefore,

$$W = 8\,P\,\rho\,t\left[\frac{P\,I}{t(1 - c^{2P})}\right]^2 \times \int\int_{R_i,0}^{R_a,\pi/2P}\left\{\left(\frac{R^{P-1}}{R_a^P}\right)^2 + (c^{2P}\,R_a^P\,R^{-P-1})^2\right\}R\,dR\,d\theta$$

Integrating to eliminate θ,

$$W = 8P\,\rho\,t\left[\frac{PI}{t(1 - c^{2P})}\right]^2\frac{\pi}{2P}\int_{R_i}^{R_a}\left\{\frac{R^{2P-1}}{R_a^{2P}} + C^{4P}\,R_a^{2P}\,R^{-2P-1}\right\}dR$$

$$W = \frac{4\,\pi\,P^2\,\rho\,I^2}{t(1 - c^{2P})^2}\left|\frac{R^{2P}}{R_a^{2P}\,2\,P} - \frac{c^{4P}\,R_a^{2P}\,R^{-2P}}{2\,P}\right|_{R_i}^{R_a}$$

$$W = \frac{2P\,\pi\,\rho\,I^2}{t(1 - c^{2P})^2}\left\{\frac{R_a^{2P} - R_i^{2P}}{R_a^{2P}} - \frac{c^{4P}\,R_a^{2P}}{R_a^{2P}} + \frac{c^{4P}\,R_a^{2P}}{R_i^{2P}}\right\}$$

$$W = \frac{2P\,\pi\,\rho\,I^2}{t(1 - c^{2P})^2}\left\{(1 - c^{2P}) + c^{4P}\,R_a^{2P}\,\frac{(R_a^{2P} - R_i^{2P})}{R_a^{2P}\,R_i^{2P}}\right\}$$

$$W = \frac{2P\,\pi\,\rho\,I^2}{t(1 - c^{2P})^2}\left\{(1 - c^{2P}) + c^{2P}\,(1 - c^{2P})\right\}$$

$$W = \frac{2P\,\pi\,\rho\,I^2}{t}\left\{\frac{(1 + c^{2P})}{(1 - c^{2P})}\right\}$$

But the loss as calculated assuming uniform distribution through the cross section of the ring is as follows:
Total current at any point

$$i = I\sin P\theta$$

Resistance of an incremental section

$$r = \frac{\rho\,R_a\,d\theta}{t\,W_r}$$

Loss in an incremental section

$$W = I^2\sin^2 P\,\theta\,\frac{\rho\,R_a\,d\theta}{t\,W_r}$$

Total loss in both rings

$$W = \frac{8P\,I^2\,\rho\,R_a}{t\,W_r}\int_0^{\pi/2P}\sin^2 P\,\theta\,d\theta$$

$$W = \frac{8P\,I^2\,\rho\,R_a}{t\,W_r}\,\frac{\pi}{4\,P}$$

$$W = \frac{2\pi\,\rho\,I^2}{t}\,\frac{R_a}{R_a - R_i}$$

$$W = \frac{2\pi\,\rho\,I^2}{t}\,\frac{1}{1 - c}$$

Therefore, the correction factor to be applied to the conventional method is the quotient of the new method over the old method.

$$K_{ring} = \frac{\dfrac{2\,P\,\pi\,\rho\,I^2}{t}\left(\dfrac{1 + c^{2P}}{1 - c^{2P}}\right)}{\dfrac{2\,\pi\,\rho\,I^2}{t}\left(\dfrac{1}{(1 - c)}\right)} = P\,(1 - c)\,\frac{(1 + c^{2P})}{(1 - c^{2P})}$$

where

P = pairs of poles

Then the formula for secondary resistance derived in appendix I should be corrected,

$$r_2 = [(CKw)^2\,\rho\,\phi]\left\{\frac{\sqrt{W^2 + SK^2}}{S_c\,S_s\,\%\text{Cond}} + \frac{0.637\,D_r}{S_r\,p^2\,\%\text{Cond}}\,K_{ring}\right\}$$

(This equation is the only one in appendix III in which p = number of poles.)

Reference

Induction Motor Core Losses, P. L. Alger and R. Eksergian. A.I.E.E. Jl., v. 39, Oct. 1920, p. 906–20.

Inspection and Tests of Explosion Proof Motors

Standards for inspection and test of electrical equipment for use in hazardous locations have been developed by the Underwriters' Laboratories. As the result of extensive research, considerable information has been made available on the explosion proof characteristics of motors and other electrical equipment in locations where there are highly flammable gases, volatile liquids, or other substances. Particular attention is given in this paper to explosion proof motors when subjected to that group of gases or vapors which have the lowest explosion hazard.

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THE development of motors and other electrical equipment designed especially for use in locations where there is danger of explosion has necessitated the formulation of standards for inspection and test of such equipment. Such standards have now been developed to the stage where they make it possible to predict accurately whether or not electrical equipment can be operated safely in locations where flammable volatile liquids, or highly flammable gases, or other substances may be present. The methods of inspection and test of electrical equipment are considered in this paper, particularly as applied to the enclosed air or fan cooled explosion-proof motor, which has rapidly proved to be practical and efficient in the field for which it was designed.

History

Not many years ago it was the practice of insurance underwriters and inspection authorities to prohibit the use in hazardous locations of motors and other electrical equipment having sparking or arcing contacts. The ordinances of many states made provisions for the segregation of electrical equipment in nonhazardous areas. Such provisions, however, were not always uniform or effective. In some cases ruling extended to squirrel cage induction type motors, which normally were considered safe, but which might cause trouble in event of breakdown of windings due to mechanical injury or the action of vapors on the insulation.

Often more serious fires and explosion hazards were introduced by the substitution of objectionable methods of power application. The removal of the motor to what was considered a safe distance from the hazardous location and the driving of the machinery by extended shafts or belts often involved the use of fast moving belts with their property of generating static electricity, and of forms of bearings which became overheated if neglected. In practice, the openings for shaft and belt could not be made gastight. In some cases attempts were made to protect the electrical equipment from hazardous gases by the use of so-called "vapor tight" housings. Many of these installations not only failed to provide the necessary fire protection, but gave a false sense of security.

With the development of the explosion proof motor it was of increasing importance to define more clearly and to classify hazardous locations as well as to provide standards of construction and test not only for the protection of property, but also the safety of human life. It is the function of Article 32 of the "National Electrical Code" to define and classify hazardous locations in order that the inspection authority enforcing the code may judge as to the need of explosion proof equipment in any area. In Article 32, locations where flammable gases or vapors are judged to be present in dangerous quantity are designated as class I. Probably one of the most important applications of Article 32 is to the dry cleaning industry, where some sections of the building are usually charged with naphtha vapors. However, as it often requires careful inspection work to determine the extent of the hazardous area in a plant, it is obvious that all installations cannot be definitely covered by rules, and much has to be left by Article 32 to the decision of the inspection authority.

Considering the standardization of motors and other electrical equipment for use in class I locations, the first standard in the United States on explosion proof motors for use in mines was published in 1912 by the U.S. Bureau of Mines. Much of the work on standards for electrical equipment for use in hazardous locations in the industries has been done by the Underwriters' Laboratories. Recently the Bureau of Mines and manufacturers of electrical equipment in the United States have co-operated with the Underwriters' Laboratories in investigations of the explosion hazards of electric motors and control equipment, for use in that group of gases and vapors which has the lowest explosion hazard (referred to as group *D*). Further research by the National Electrical Manufacturers Association and the Underwriters' Laboratories looking toward the development of additional data on equipment for use in the more hazardous atmospheres and also on the use of fused equipment in hazardous locations is now under consideration. Not only has considerable effort and expense been devoted by manufacturers to the development of electrical equipment which would satisfy the exacting requirements of safety, but also

A paper presented at a meeting of the St. Louis (Mo.) Section of the A.I.E.E. Nov. 21, 1934, and recommended for publication by the A.I.E.E. committee on electrical machinery. Manuscript submitted Jan. 28, 1935; released for publication May 10, 1935.

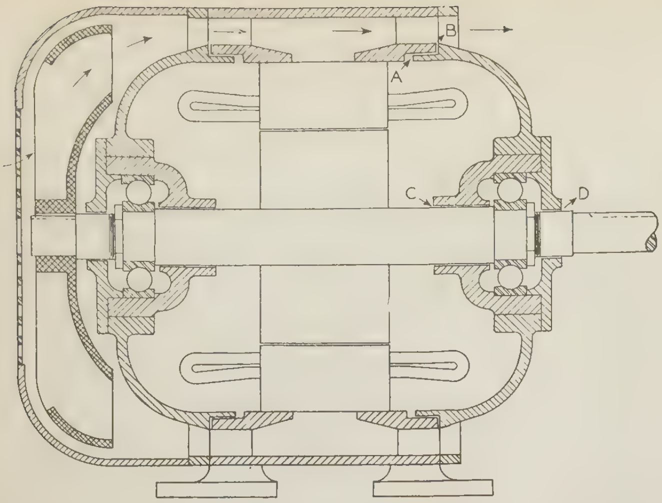

Fig. 1. Cross section of a modern type of fan-cooled explosion-proof motor

to provide equipment that is practical and efficient at a reasonable cost to the user.

Explosion Proof Type of Construction

The usual type of electric motor for use in ordinary locations as distinguished from class I locations is so constructed that the surrounding air may pass freely through the interior, and consequently if an explosive gas is present, it may be ignited by a spark from the moving contacts, such as brushes or slip rings, or from short circuit caused by injured or defective insulation, or by high temperatures from overload or burn-out.

In designing a motor for use in class I locations the most obvious method would be to employ a gas tight enclosure to prevent the entrance of flammable gas or vapor, thus removing the danger of internal ignition from arcing or sparking contacts. Although it is practical to construct enclosures for motors which prevent the entrance of appreciable quantities of dust, the only way to insure the exclusion of gases is to seal the enclosure hermetically, which is impractical. Even if hermetically sealed when new, the motor enclosure would not under service conditions remain gas tight very long, particularly at the shaft entrance.

The use of gasket materials such as rubber to make a motor enclosure permanently gas tight does not appear to be promising.

Since it is impractical to construct gas tight motors, the problem is to so construct the motor or other electrical equipment for class I locations that if gas or vapor within the enclosure is ignited, the resulting flame is prevented from passing to the surrounding atmosphere. This is one of the fundamental requirements for motors and other electrical equipment of the explosion proof type. The design of equipment to meet this requirement is based upon the principle that the propagation of flame through an opening is prevented when the dimensions of the opening are within certain narrow limits. It is not surprising, therefore, that considerable effort has been devoted by manufacturers to the design of the openings in enclosures for explosion proof equipment.

Openings in the Enclosure

Figure 1 shows in section a modern type of fan-cooled explosion proof motor. A type of end shield joint is shown at *A-B*. A form of shaft opening in the casing is shown at *C-D*. For convenience, the

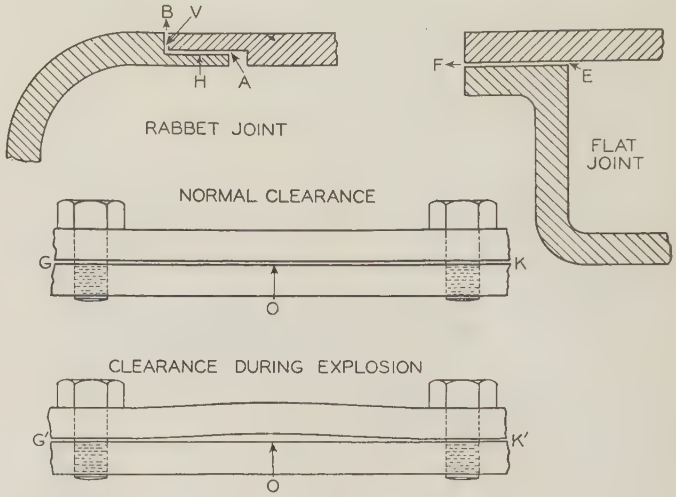

Fig. 2. Details of different types of joints

distance *A-B* is termed the "length of flame path." The unoccupied space in the enclosure is known as the "free space" or "free volume."

Suppose that the motor is surrounded by an explosive gas which diffuses through these openings or clearances, filling the free space inside of the enclosure; assume now that ignition of the gas in the enclosure occurs. Naturally the flame spreads and pressure is produced by the expansion of gaseous products of combustion caused by the heat of the reaction. If the length of the path at the joints is long enough, and the clearance is small enough the flame will be arrested between *A* and *B*, thus preventing ignition of the surrounding atmosphere.

In general, within certain narrow limits, the less the clearance, the less the length of metal path required to arrest flame. No fundamental or mathematical formula has been established for this relationship. Much depends upon the type of opening.

It will be noted that the type of openings shown at the end shield joints are typical forms of rabbet joints.

Figure 2 gives in detail a rabbet joint, and also shows a flat joint. The rabbet joint is more effective than the flat joint in arresting flame, other factors assumed to be equal. This is accounted for on the basis that there is a more abrupt change at a rabbet joint in the direction of flame propagation. For a given clearance, therefore, a longer path is required to arrest flame at a flat joint than at a rabbet joint. An even more effective type of joint for arresting flame is the threaded joint, 5 full threads being an excellent flame arrester.

In the case of shaft openings, the diameter of the shaft as well as the clearance and the length of metal path influence the arrest of flame. The opening at a shaft of small diameter, other factors assumed to be equal, is more effective than the opening at a large one. Further, when the shaft is revolving, the length of path required to arrest flame is much less than when the shaft is stationary.

Time will not permit a discussion of all the various details relating to explosion proof joints. In passing, it is important to note that the clearance at an explosion proof joint is increased more or less during the explosion by the pressure effect. This is illustrated in figure 2 at *O*. This increase in clearance depends upon the explosion pressure, the strength of the enclosure, and the bolt spacing. It does not appear feasible to predict accurately from consideration of construction details the increase in clearance that may occur at a joint during an explosion. A number of failures in explosion tests on account of the increase in openings at joints have occurred with equipment otherwise meeting rigid specifications as to dimensions of joints.

Returning now to the general requirement that explosion proof equipment must be of such design that the flame is prevented from passing from the interior of the enclosure to the surrounding gases outside, it will be seen that all openings in the enclosure, including those at the shaft and joints, must be of such dimensions that the flame from an explosion will be arrested.

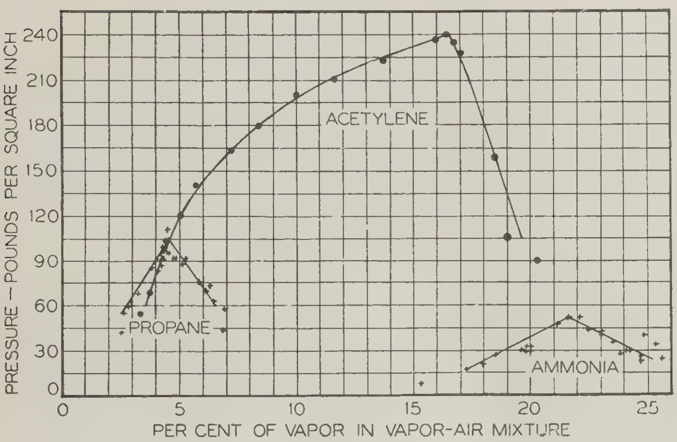

Fig. 3. Explosion pressure curves for mixtures of 3 different gases in air

Other Details of Enclosure

Strength of Enclosure. It is equally important that the enclosure itself shall be of substantial construction in order to meet service requirements and have sufficient strength to withstand without appreciable distortion or rupture the maximum internal pressures that may be developed by an explosion of the gases or vapors in the presence of which the equipment is to be used. Owing to the unavoidable variations in materials and in manufacturing operations, a calculated factor of safety of 5, based upon the maximum pressure obtained in explosion tests, is required.

Bolts and Bolt Holes. It is evident that the bolts employed for the assembly of the enclosure shall be of adequate strength and so spaced as to prevent a dangerous increase in clearance during an explosion. The standard of the Underwriters' Laboratories has been criticized because it does not require all bolt holes to be bottomed, on the theory that if a bolt is omitted, protection will be provided by this means. The omission of a bolt at the joints, irrespective of whether the bolt hole is bottomed, is liable to permit a dangerous increase in the clearance during an explosion. Further, it is not practical to produce explosion proof equipment which is fool proof to the extent that it cannot be disassembled. Reasonable care and maintenance must be assumed. The design and test performance required by these standards calls for a form of construction which is as nearly fool proof as appears to be practicable. It is safe for use under various conditions as long as the enclosure is maintained intact.

Leads. The leads or conductors must be tightly fitted or sealed and securely held in place where they pass into the enclosure.

Free Volume of Enclosure. The unoccupied space or free volume of an enclosure is another important factor in the design of an explosion proof enclosure. The explosion pressure, within certain limits, will depend largely on the amount of free volume. If the free volume is extremely large, a pressure wave known as "detonation" may develop, as will be seen later. It is hardly practical to construct electrical enclosures to withstand detonations, but it is practical to make enclosures having free volume small enough to avoid the danger of detonations in the case of the most common gases.

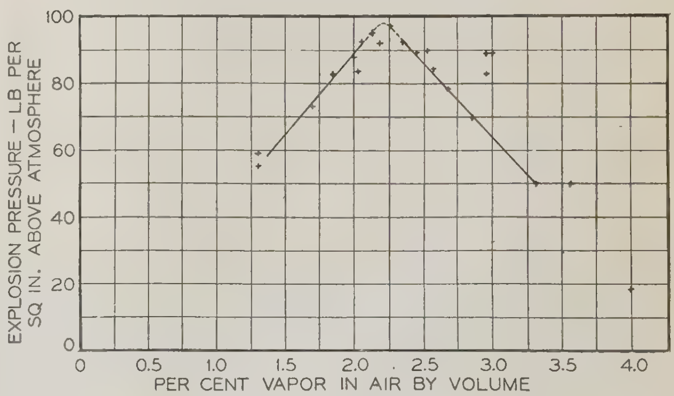

Fig. 4. Explosion pressure curves of gasoline vapor in air

Shape of Enclosure. It is of great importance in the design of enclosures to avoid forms of construction that divide the free volume into communicating compartments, which may permit abnormally high explosion pressure effects known as "pressure piling." This phenomenon is accounted for on the basis that an explosion beginning in one compartment of the enclosure may cause compression and

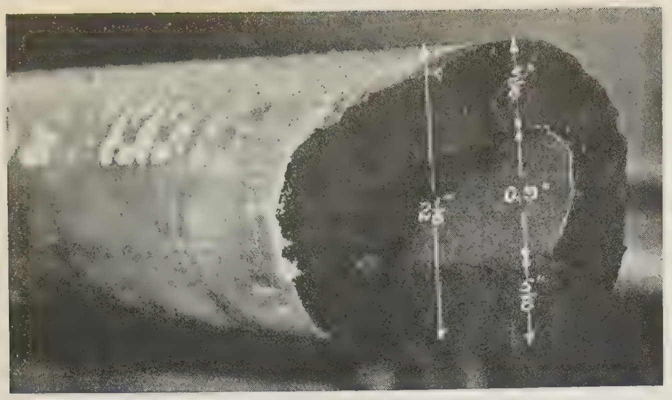

Fig. 5. Section of extra heavy iron pipe after rupture by explosion

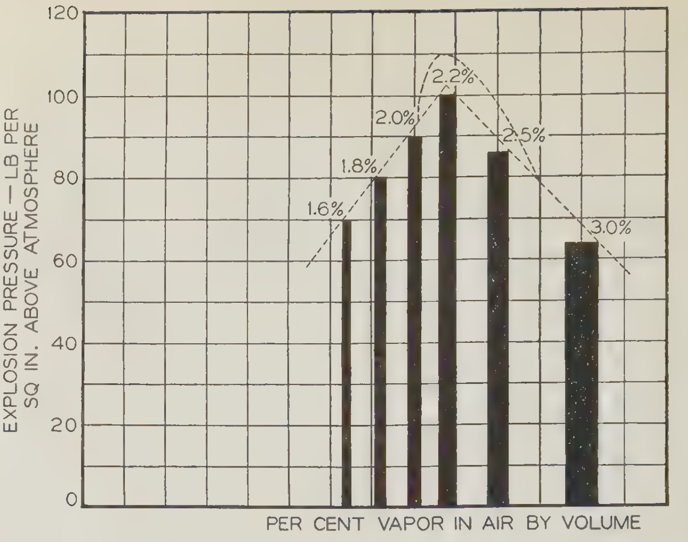

Fig. 6. Explosion pressure curves of gasoline vapor in air. The width of the columns represents roughly the duration of the flame

turbulence of the gaseous mixture in the other compartment in advance of the flame. As will be seen later, turbulence raises the explosion pressure of a gaseous mixture. Further, the advancing flame front from one compartment may ignite the already turbulent and more or less compressed mixture in the other compartment simultaneously at a large number of points.

Electrical Requirements

Motors and other explosion proof equipment for use in class I locations must comply with established electrical requirements covering electrical equipment for use in ordinary locations. Space does not permit a discussion of the required electrical characteristics of such equipment, but in passing it may be mentioned that it is particularly important in the design of explosion proof equipment to have the spacing between parts of opposite polarity and of live parts and enclosure adequate. The danger of ignition of the surrounding gases, which might result from a destructive short circuit, is evident. It is to be noted in this connection that spacing of live parts that is adequate for air filled enclosures may not be sufficient in the case of an enclosure filled with burning gas because flame is accompanied by ionization with consequent increase in the electrical conductivity of the gases between live parts.

It is recognized that motors under certain conditions of service due to mechanical injury or the action of vapors on insulation are subject to burn-out, and it is required, therefore, that motors of the explosion proof type be of such form of construction that if a burn-out occurs the enclosure does not reach a dangerous temperature.

Explosion Proof Equipment Other Than Motors

The preceding discussion refers for convenience particularly to the type of construction employed for explosion proof motors, as it would take much too much space to go into the details of construction of the various forms of explosion proof electrical equipment. In general, however, the principles employed in the design and construction of explosion proof enclosures for motors also apply to other forms of explosion proof equipment with the exception of equipment of the oil immersed type. Thus, it is clear that in any form of electrical explosion proof equipment with the exception of the oil immersed type protection is provided by means of a substantial enclosure, as is done in the case of a motor. Openings in the enclosure for push rods or shafts are protected in a manner similar to that employed for the shafts of motors. In the case of explosion proof lighting fixtures, both glass and metal parts are used, the enclosure being made of part metal and part glass. Glass-to-glass and glass-to-metal as well as metal-to-metal paths at openings are employed to arrest flame.

In the case of oil immersed equipment all connections, terminals, and arcing parts are immersed in oil to a sufficient depth to prevent ignition of the surrounding gaseous mixture. Where the conditions of operation are such as to cause the evolution of appreciable quantities of gas from the decomposition of the oil used, provision must be made for adequate ventilation. If an explosion proof enclosure is employed in addition to the oil immersion, the strength of such an enclosure must be sufficient to withstand explosions of the gases produced by the decomposition of the oil, provided that such gases are generated in sufficient quantity to form explosive mixtures within the enclosure.

Class I Locations Divided Into 4 Hazard Groups

The length of the paths of openings in enclosures of explosion proof equipment and also the strength of the enclosure required to prevent the propagation of flame to the outside surrounding gas depends upon the nature of the gas in which the equipment is intended for use. While inflammable or explosive gases and vapors have in common certain definite chemical and physical properties, there is a wide difference in the explosive properties of many of

them, particularly as to the rate of flame propagation and maximum explosion pressure. It will be noted from figure 3, which shows the explosion pressure curves for mixtures of acetylene, propane, and ammonia with air, that the maximum explosion pressure of acetylene is much higher or more violent than that of ammonia or propane. As will be seen later, the maximum pressure of propane is of the same general order as that of gasoline. It will be clear, therefore, that a motor casing or enclosure of sufficient strength for propane would not necessarily be safe for use with acetylene.

It may then be asked, "Why not design a motor or other electrical equipment for use with the most explosive gas met with in practice?" Theoretically this would be an excellent solution of the problem. It would make unnecessary the manufacture of different designs of motors or other explosion proof equipment, but like many theories it cannot be satisfactorily applied in practice, particularly from an economical standpoint. For example, a motor constructed for safe use in acetylene gas would be far more expensive and massive in construction than a motor for use in gasoline vapor.

As the differences in explosive effects of many of the common gases and vapors are sufficient to call for different forms of construction of explosion proof electrical equipment, it appears the most practical and logical course is first to divide common gases or vapors into groups in accordance with their explosion hazards, and second to base the test requirements on the group in which the equipment is designed to operate. A tentative grouping of common gases and vapors in respect to the explosion hazard, therefore, has been worked out with the thought that it might be expanded or limited in the light of further experience. Four groups, *A*, *B*, *C*, and *D*, are included:

Group *A* is the most hazardous. It represents explosive properties of the order of those of acetylene.

Groups *B*, *C*, and *D* represent gases and vapors of successively lower explosion hazards. The hazards of group *C* are of the order of those of ether, and the hazards of group *D* are of the order of those of gasoline.

The exact classification of hydrogen has not been finally determined, but it is tentatively placed in group *B*. It may later be found to belong in group *C*. As accumulation of explosion data increases, it may even be possible to reduce the number of groups. In the meantime, however, it is necessary in the interests of safety to employ the above grouping. There are a number of other gases and vapors besides those of gasoline which fall into group *D*. Among these are methane, the vapors of the various petroleum distillates, the various alcohols, acetone, common pyroxylin solvents, and benzene.

Explosion Tests

It should be clear from the foregoing that it would be difficult to cover adequately in one standard all details of the various features of construction on which the safety of explosion proof equipment depends. Such a standard would permit little, if any, leeway in the design of explosion proof equipment, and would hamper progress in manufacture. The standards of the Underwriters' Laboratories on explosion proof equipment, therefore, while covering fundamental features of construction, consist mainly of performance requirements, including explosion tests.

The purpose of the explosion tests is to demonstrate whether the equipment under examination is so constructed as not to cause under conditions of operation the ignition of surrounding gases or vapors of the "hazard group" for which it is intended for use. The explosion tests, therefore, serve as a final criterion for acceptance or rejection of the electrical equipment submitted to the Underwriters' Laboratories. It is clearly of the highest importance that the test procedure employed be practical in its application and fully dependable. It must therefore be based upon the fundamental principles of flame

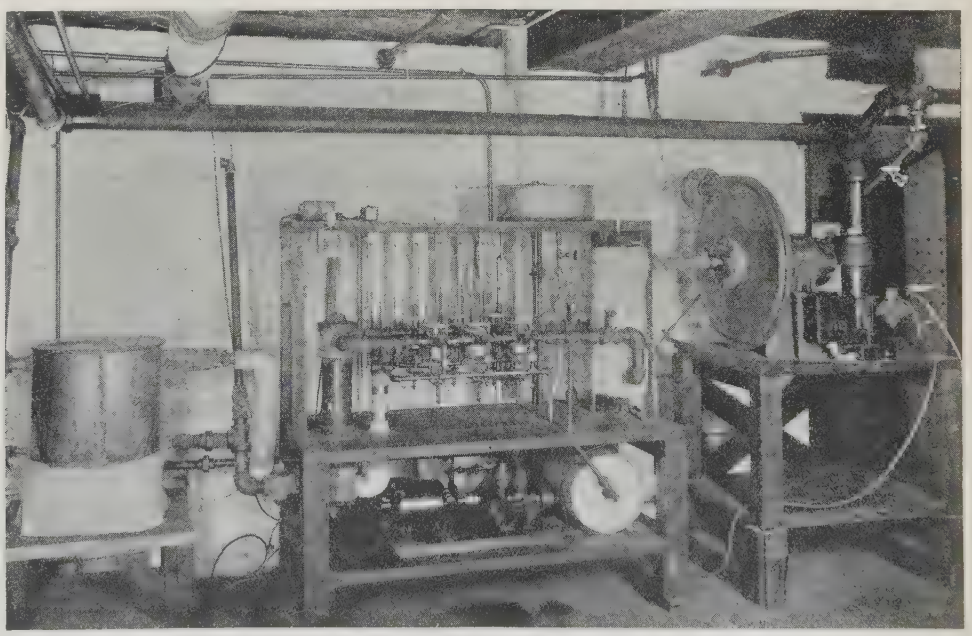

Fig. 7. Apparatus for giving a constant predetermined mixture of vapor and air in large volume over a comparatively long period of time, for use in explosion tests

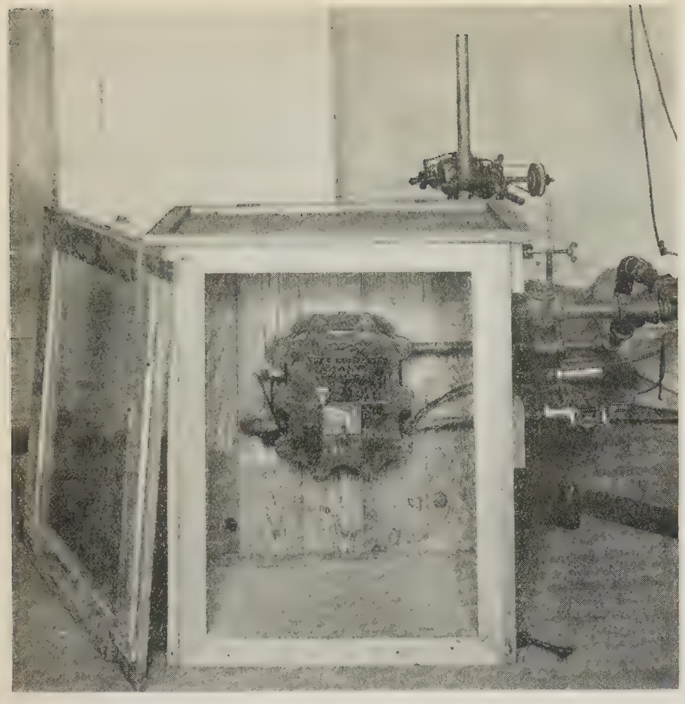

Fig. 8. An actual explosion test installation connected to the power line

propagation that apply to explosion proof equipment. These principles, which will now be discussed briefly, relate primarily to the development of the explosion pressure and the propagation of flame through openings in an enclosure.

It has already been noted that the violence of an explosion or the pressure developed depends upon the nature of the gas or vapor causing it, other factors assumed to be equal, and accordingly common explosive gases or vapors have been divided into several groups as previously discussed. The results of explosion tests of an electrical enclosure with a gas or vapor of one group does not cover safety of operation in a gas of a more explosive group, and it is therefore the practice to conduct the tests in a gas or vapor representing the group in which the electrical equipment is intended for use.

Concentration for Maximum Pressure

It is to be noted, however, that all explosions of the same gas or vapor are not necessarily alike. Explosions of acetylene, for example, may be weak developing little pressure, or violent developing a high pressure. It is therefore important to have the explosion tests of an electrical apparatus with a particular gas or vapor develop the full explosion pressure characteristic of the gas or group of gases in which the equipment is intended for use.

By referring again to figure 3, it will be seen that the explosion pressure of any of the gases included depends upon the concentration of the gas in air. For example, a low percentage of acetylene or of propane in air gives a low explosion pressure. A very high percentage of acetylene or propane may also give a low pressure. It will be noted further that the percentage of acetylene (its concentration in air) which gives a peak explosion pressure is different from the concentration of propane or of ammonia which gives a peak pressure.

Figure 4 shows the explosion pressure curve of gasoline. It will be noted that the concentration or per cent of gasoline vapor in air which yields maximum pressure is approximately 2.2.

Turbulence

The explosion pressure curves shown are based upon quiescent mixtures, and while they illustrate the importance of the relation between the pressure effect and the concentration of gas or vapor, they do not record the highest explosion pressure obtainable under all conditions with the gases included. If the explosive mixture is in a state of mechanical agitation or turbulence at the time of ignition, a somewhat higher explosion pressure is developed. This is accounted for on the basis that the motion of the gas speeds up the flame progagation. Some forms of explosion proof electrical equipment, such as motors, when in operation cause a marked turbulence of a gas within the enclosure, and it is important, therefore, to have such equipment in operation during some of the explosion tests.

Intensity and Location of Source of Ignition

The intensity and location of the source of ignition also influence flame propagation within an enclosure. Having a point of ignition near a flame path at a joint or other opening causes the flame to propagate more readily to the outside. In many of the explosion tests the use of a spark plug properly located for effective ignition inside the enclosure has the advantage of saving much time. In the case of some types of explosion proof equipment, such as circuit breakers, which may yield intense arcs, it is necessary in order to duplicate operating conditions to depend upon the device itself for ignition of the explosive mixture. Judgment is often required in choosing the method of ignition to be employed in order to obtain the element of danger to be anticipated under service conditions.

Detonation

The phase of flame propagation known as "detonation," which is characterized by a flame travel of a much higher speed and a pressure effect of a much higher order than occurs in ordinary explosions, is possible under conditions where the concentrations of the gas-air mixture are in certain proportions, provided that the free volume of the explosion proof enclosure is large enough. Fortunately, the free volume required to produce a detonation of most of the common gases and vapors is much larger than it is necessary to employ in the construction of ordinary explosion proof equipment. It is to be noted in this connection, however, that detonations of acetylene may occur in a much smaller space than is the case with other common gases and vapors.

Figure 5 is a photograph of a section of extra

heavy iron pipe ruptured in the explosion laboratory by a detonation of acetylene. Apparatus was not available for recording the pressure developed, which was evidently of a high order. The initial pressure of the acetylene in this experiment was higher than would be likely to occur in electrical enclosures, but this does not change the significance of the result. Time will not permit a detailed discussion of this phenomena, but it is clear that there is a definite safety limit to the free volume of explosion proof enclosures, particularly of those designed for use in group *A*.

Flames Difficult to Arrest

The concentration of gas or vapor in air which gives the maximum explosion pressure does not necessarily produce the flame which is most difficult to arrest at openings in the enclosure. In other words, it would not be sufficient for the purpose to test an enclosure only with the mixture or concentration of vapor in air giving the highest explosion pressure. It has been found that mixtures containing approximately 1.8 per cent by volume of gasoline vapor in air are much more likely to produce discharge of flame at the joints or other openings than mixtures of the order of 2.2 per cent by volume.

Before data now available on the different explosions that may be produced by gasoline vapor in air were obtained, it was necessary to include a large number of explosion tests in order to be certain that the explosive range was fully covered. By referring again to figure 4 it will be seen that at least 60 or 70 explosion tests would be necessary to cover the effective part of this range.

It is possible to duplicate under the test conditions now employed any of the more dangerous explosions that may be produced by gasoline vapor. In the chart, figure 6, the column marked "2.2 per cent" represents an explosion giving the maximum pressure, while the column marked "1.8 per cent" represents an explosion giving less pressure but giving a flame which is more difficult to arrest than the flame of the explosion represented by the column "2.2 per cent." The width of the columns represents roughly the duration of the flame during the kinds of explosions shown. The main dotted line represents the explosion pressure curve for gasoline (see figure 4). The short dotted line at the top of the curve refers to a small variation in the explosion pressures of gasoline that has never been accounted for. In any case a sufficient number of explosion tests to include this variation must be conducted to obtain dependable results.

Table I—Summary of Main Items Included in Underwriters' Standards on Motors and Other Electrical Equipment for Use in Class I Locations

1.	Length of path and clearance at	shaft push rod
2.	Length of path and clearance at joint	rabbet flat threaded
3.	Number of threads of joint	
4.	Explosion proof enclosure or casing	thickness strength free space shape
5.	Adequate bolting	number spacing clearance strength
6.	Electrical requirements	spacing of parts "National Electric Code" rules
7.	Bottomed holes for	name plate electrical mechanism
8.	Class I group	
9.	Performance in tests	electrical explosion
10.	Marking and rating	

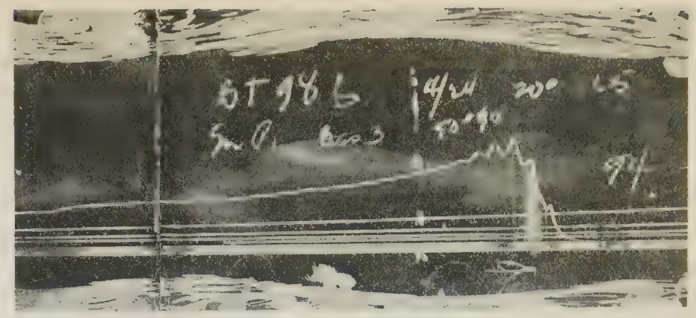

Fig. 9. A typical time-pressure record of an explosion test

Control of Test Concentrations

In order to obtain the necessary control of the concentrations of vapor and air for the explosion tests without undue expenditure of time and work it is necessary to employ special equipment, the development of which required a number of years of experimental work. The amount of time saved by such equipment appears to have justified the labor involved in its development, and it is with some degree of satisfaction that figure 7, showing the apparatus called "the carburetor," is shown. This carburetor is capable of giving a constant predetermined mixture of vapor and air in large volume over a comparatively long period of time. With this apparatus and accumulated data as to the effects of the various explosion mixtures in terms of pressure as well as in terms of flame propagation at joints, it has been possible to a considerable extent to reduce safely the number of explosion tests necessary to determine whether a given electrical apparatus could be expected to function safely in an explosive atmosphere.

Other Test Conditions

Finally, it is essential that the conditions of the explosion tests be comparable with dangerous conditions as met with in practice. To accomplish this, the motor or other electrical equipment for test is tapped with threaded holes for attachment of a spark plug, a time pressure recording device and pipe connection to the carburetor, and installed in an explosion box, which is also connected to the

carburetor. Outlet connections are provided for the electrical enclosure and the explosion box in order to permit the displacement of the original air in both by the explosive mixture of gas or vapor.

Figure 8 is a photograph of an actual test installation which is connected to the power line. The front of the explosion box, which contains the explosive mixture surrounding the electrical enclosure, is made of readily replaceable transparent material to enable an observer, protected by sand bags, to note, first, whether an explosion in the electrical enclosure causes ignition of the surrounding explosive mixture in the box; and second, in case of ignition of the surrounding mixture does not occur whether dangerous sparks or flame are discharged from any of the openings of the electrical enclosure.

In case the surrounding mixture in the box is ignited, the electrical equipment has failed to meet the tests. If the surrounding mixture is not ignited but the visible discharge of dangerous sparks or flame from the openings in the enclosure occurs, it is safe to conclude that the danger of failure has been reduced to a considerable extent, but that the margin of safety provided, if any, is inadequate. A typical time-pressure record of such a test is shown in figure 9.

A brief summary of the main features included in this discussion is given in table I.

Inspection at Factory

Inspections at factories by engineers of Underwriters' Laboratories are made of listed equipment. The listing of explosion proof equipment is restricted to such forms of construction as have been found by the examination and explosion tests to meet with the standard. It is not necessary or practical to test every individual unit manufactured, provided that the same design and form of construction as that originally submitted is employed.

When inspection service on listed explosion proof equipment is first inaugurated at a factory, 100 per cent of the output is examined. The frequency of inspections subsequently depends largely upon the volume of production and the conditions at the plant.

When necessary, an inspector is first given training in the explosion laboratory at Chicago. He is provided with a guide containing detailed information as to the items to be covered in the inspection. In some cases there are special features in the forms of construction employed, but in general items 1 to 7, inclusive (table I) also item 10, are covered in more or less detail by the inspector.

A label is attached to explosion proof motors found to meet the requirements. By means of this label listed motors of the explosion proof type of construction may be recognized wherever found. The explosive atmosphere in which the motor is intended for use is covered by the group designation on the label.

As long as the labeled motor enclosure is maintained intact, safety of operation is assured. Machinery in general and particularly when equipped with safety devices to prevent accidents to workmen requires more or less supervision. Likewise, electrical equipment in connection with machinery for use in hazardous locations requires reasonable supervision to safeguard against its improper use, which might result in serious losses or accidents.

The importance of providing electrical equipment for safe use in explosive atmospheres need not be dwelt upon. Loss of human life as well as loss of property by fire and explosion is involved which fully warrants the added expense incident to the installation of explosion proof equipment in locations where dangerous atmospheres may exist.

Operational Solution of Electric Circuits

In the ordinary method of solving electrical networks by means of the operational calculus, the equations usually are written with the restriction that the initial conditions be rest conditions, thus reducing considerably the utility of the operational calculus. In this article a method has been applied to the solution of electrical networks wherein the initial conditions may be either rest or dynamic. A general solution is derived by which it is possible to write all the initial conditions into an ordinary operational equation to which the usual methods of interpretation may be applied to give the complete solution all in one stroke.

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THE Heaviside operational calculus in the past 4 years has come to be recognized as a valuable tool in the analysis of electrical networks. During this period a vast amount of literature has been published, developing and extending the subject introduced by Heaviside in his "Electromagnetic

Written especially for Electrical Engineering. Manuscript submitted July 12, 1935; released for publication Aug. 13, 1935.

The author wishes to acknowledge the assistance of M. G. Scherberg of the University of Minnesota, Minneapolis.

1. For all numbered references see list at end of article.

Theory" and "Electrical Papers." At first, its use was restricted to only a few students of mathematical physics who saw fit to use it in solving the differential equations of physics. Gradually, however, it found its way into the hands of the electrical engineer until now one has but to pick up a technical publication to find its use scattered here and there among the articles. Colleges and universities have adopted and embodied it in their texts on transient phenomena, and now it is taught not only to graduate students but to senior and recently to junior electrical engineering students.

The classical differential equation method of attack often becomes too laborious, and it is then that the operational solution is resorted to. It is an elegant compact method from the point of view of analytic form. The great advantage of the operational over the classical method is the manner in which the boundary conditions are taken into account. In the latter the boundary conditions are taken care of by constants of integration, while in the operational method they are included automatically in the solution. However, the ordinary Heaviside method in eliminating the constants of integration, automatically imposes upon the system the condition of initial rest; that is, it gives the solution on the basis that all of the initial currents and charges in the meshes of a network are zero. Therefore, when the initial conditions are not rest conditions the Heaviside formula will not give the complete solution directly. This must be obtained by adding to the result given by the formula the solution for the specified initial conditions with zero impressed driving forces. But here the ordinary operational method of solution is limited in that there is no way of setting up an operational equation containing within itself the initial conditions. This part of the solution must be carried out either by artifices known as "switching" or by resorting to the classical method.

In short, when initial arbitrary conditions exist, the method would be to superpose linearly the solution for initial rest conditions with the given driving forces upon the solution for the specified initial conditions and zero driving forces under the same switching conditions. One readily sees how this reduces the practical utility of the Heaviside formula for problems in which the initial conditions are not rest conditions, since the total labor involved would be almost twice the usual amount. It is true that several authors such as Bromwich[1] and Carson[2] have worked out rigorous treatments of Heaviside's methods in which they obtained solutions that include the initial conditions. These solutions are obtained either by integration in a complex plane or by the solution of an integral equation. In order to be able to appreciate them, one must have at his command an enlarged mathematical background beyond that which the average engineer possesses. Jeffries,[3] however, has introduced a method by which the ordinary operational equations for a system may be set up containing within themselves the inital conditions. It is the purpose of this article to extend and apply Jeffries' method to the solution of electrical networks. Thus the operational equations easily can be set up for a network of any number of meshes, which contain the initial conditions and to which, then, may be applied the ordinary methods of solution, such as the Heaviside formula, to obtain the complete solution all in one stroke.

Solution of a Simple Circuit

Consider the simple circuit of figure 1 with a steady state current $i_0 = E/R$ flowing in it. At $t = 0$ switch S is closed, short-circuiting the battery. The differential equation for the behavior of the current after $t = 0$ will be

$$L\frac{di}{dt} + Ri = 0 \text{ or } \frac{di}{dt} = -\frac{R}{L}i \tag{1}$$

A solution to this equation will be sought such as to include the inital condition of $i = i_0$ when $t = 0$. Let q denote the operation of integrating with respect to t from 0 to t such that

$$qi = \int_0^t i\,dt \tag{2}$$

Performing the operation q on both sides of equation 1,

$$q\frac{di}{dt} = \int_0^t \frac{di}{dt}dt = i - i_0 = -q\frac{R}{L}i \tag{3}$$

Equation 3 may be rewritten in the form

$$\left(1 + q\frac{R}{L}\right)i = i_0 \tag{4}$$

or

$$i = i_0 - q\frac{R}{L}i \tag{5}$$

In writing the term $q(R/L)i$ it is implied that R/L is multiplied into i and the resulting product integrated with respect to t from 0 to t. To solve equation 5, a value for i could be assumed and substituted into the right-hand part; this trial solution then

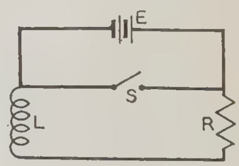

Fig. 1. A simple R-L circuit

could be checked by comparing it with the left-hand part. A more direct way would be to substitute the complete expression into the last term thus:

$$i = i_0 - \frac{qR}{L}\left(i_0 - \frac{qR}{L}i\right)$$

$$i = i_0 - \frac{qR}{L}i_0 + \frac{qR}{L}\frac{qR}{L}i \tag{6}$$

Substituting equation 5 into equation 6,

$$i = i_0 - \frac{qR}{L}i_0 + \frac{qR}{L}\frac{qR}{L}\left(i_0 - \frac{qR}{L}i\right)$$

$$i = i_0 - \frac{qR}{L}i_0 + \frac{qR}{L}\frac{qR}{L}i_0 - \frac{qR}{L}\frac{qR}{L}\frac{qR}{L}\left(i_0 - \frac{qR}{L}i\right)$$

$$i = i_0 - \frac{qR}{L} i_0 + \frac{qR}{L}\frac{qR}{L} i_0 - \frac{qR}{L}\frac{qR}{L}\frac{qR}{L} i_0 + \ldots \tag{7}$$

after repeating the substitution indefinitely.

It readily can be shown that the series converges and therefore represents a definite function. Further, this now must be shown to be the correct solution, by inserting it in equation 5. If this be done, the equation is satisfied for all values of t and, in addition, it reduces to i_0 when $t = 0$. Thus equation 7 is the true solution and can be written in the form

$$i = \left(1 - \frac{qR}{L} + \frac{qR}{L}\frac{qR}{L} - \frac{qR}{L}\frac{qR}{L}\frac{qR}{L} + \ldots\right) i_0 \tag{8}$$

The series included between the parentheses is the binomial expansion of $(1 + qR/L)^{-1}$ carried out as if qR/L were a mere algebraic number. Hence equation 8 may be written in the form

$$i = \frac{i_0}{1 + \frac{qR}{L}} \tag{9}$$

provided the operator $(1 + qR/L)^{-1}$ be expanded by the binomial theorem before interpreting it. Equation 9 gives a shorthand way of writing equation 8. But now comparing equation 9 with equation 4, it may be seen that equation 9 is also what would have been obtained had the solution of equation 4 been carried out as if $(1 + qR/L)$ were an algebraic number. The interpretation of the operational solution, equation 9, requires rules for interpreting rational functions of q operating on unity and other functions. By interpretation is meant a transformation that converts the solution of i into a function of t no longer involving q. Equation 9 now will be interpreted directly by means of equation 8.

Since i_0 is a constant,

$$-\frac{qR}{L} i_0 = -\frac{1}{L}\int_0^t R\, i_0\, dt = -\frac{Ri_0}{L} t = \left(-\frac{R}{L} t\right) i_0$$

$$\left(-\frac{qR}{L}\right)\left(-\frac{qR}{L}\right) i_0 = -\frac{1}{L}\int_0^t R\left(-\frac{Ri_0 t}{L}\right) dt = \left(-\frac{R}{L} t\right)^2 \frac{i_0}{2}$$

and so on until finally equation 8 becomes

$$i = i_0\left[1 - \frac{R}{L} t + \frac{\left(\frac{R}{L} t\right)^2}{2!} - \frac{\left(\frac{R}{L} t\right)^3}{3!} + \ldots\right]$$

$$i = i_0 e^{\frac{-Rt}{L}} \tag{10}$$

which is the solution sought. Therefore the expression

$$\frac{1}{1 + \frac{qR}{L}}$$

operating on i_0 (a constant) is equivalent to multiplying i_0 by $e^{\frac{-Rt}{L}}$. This is the meaning and interpretation attached to this expression. At this point it is desirable to make a change in notation.

$$\text{Replace } q \text{ by } \frac{1}{p} \tag{11}$$

Inserting equation 11 into equation 9,

$$i = \frac{i_0}{1 + \frac{1}{p}\frac{R}{L}} = \frac{Lp\, i_0}{Lp + R} \tag{11a}$$

This form of equation is well known, and it is recognized immediately that

$$\frac{Lp}{Lp + R} i_0 = i_0 e^{\frac{-Rt}{L}}$$

Therefore $\frac{Lp}{Lp + R}$ has the same meaning as $\frac{1}{1 + \frac{qR}{L}}$

Consequently it is not necessary to set up a new set of rules for interpreting operational equations in q.

One may go back to equation 9 or 4 and write

$$\left(1 + \frac{R}{pL}\right) i = i_0$$

or treating p as a constant,

$$(R + pL)i = pLi_0$$

or finally,

$$Ri + pL(i - i_0) = 0 \tag{12}$$

But this is equivalent to equation 1 with the additional insertion of $p(i - i_0)$ for di/dt, thus including the initial condition that $i = i_0$ when $t = 0$.

Expressions of the form of equation 9 are to be interpreted as having the meaning indicated in equation 10. However, by virtue of relation 11, equations 9 and 11a are equivalent so that therefore

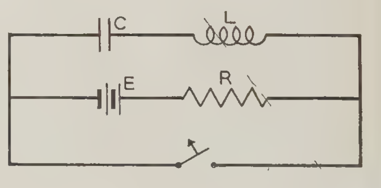

Fig. 2. A simple R-L-C circuit

equation 11a may be used; this is more convenient provided it be kept in mind that equation 11a is merely another way of expressing equation 9, which is interpreted to mean solution 10.

Note that no mention has been made of the meaning of p other than to consider it merely as an operator having certain special properties already familiar to users of the Heaviside calculus. If therefore the original equation be written in the form

$$(b_1 p + c_1)\, i = 0$$

the new operational equation will be:

$$(b_1 p + c_1) i = p b_1 i_0$$

which contains the initial conditions. Note that the initial condition was introduced into the operational equation by an actual integration process in equation 3. The procedure thus is based upon the conventional method of integrating differential equations. If this equation now be solved by ordinary

nethods, it will yield the complete solution for the urrent in the circuit.

The Problem Extended

The problem now will be extended to the circuit of igure 2. Suppose that at the instant the switch is pened the capacitance C is charged to a potential V_c and the initial current is i_0. The differential equaion will be:

$$L\frac{di}{dt} + Ri + \frac{1}{C}\int i\,dt = E \tag{13}$$

Differentiating this equation to eliminate the inteal sign,

$$L\frac{d^2i}{dt^2} + R\frac{di}{dt} + \frac{i}{C} = 0 \tag{14}$$

This equation shall be the starting point; a solution o it will be sought.

Applying the operator q to each of the terms,

$$qL\frac{d^2i}{dt^2} + qR\frac{di}{dt} + \frac{qi}{C} = 0$$

$$L\int_0^t \frac{d^2i}{dt^2} + \int_0^t R\frac{di}{dt}\,dt + \frac{1}{C}\int_0^t i = 0 \tag{15}$$

Evaluating the parts of equation 15,

$$L\left[\frac{di}{dt} - \left(\frac{di}{dt}\right)_0\right] + R(i - i_0) + \frac{q}{C}i = 0$$

where the subscript 0 denotes the values for $t = 0$, he initial conditions. Applying the operator q once nore,

$$qL\frac{di}{dt} - qL\left(\frac{di}{dt}\right)_0 + qRi - qRi_0 + \frac{q^2i}{C} = 0$$

$$L(i - i_0) - q\left[Ri_0 + L\left(\frac{di}{dt}\right)_0\right] + qRi + \frac{q^2i}{C} = 0$$

or

$$Li + qRi + \frac{q^2i}{C} = q\left[Ri_0 + L\left(\frac{di}{dt}\right)_0\right] + Li_0 \tag{16}$$

Equation 16 is analogous to equation 4; therefore, t can be evaluated in exactly the same manner as was equation 4 or 5. In this way, another infinite series could be built up analogous to equation 8 whose terms would contain q's and other quantities R, L, and C. This series then could be evaluated by ntegrating with respect to time, between limits 0 and t, everything in front of a q wherever a q occurred in the series. The resulting series would be the comolete solution.

However, as may be seen from equations 8, 9, and 4, it is not necessary to go through all this work. A shorthand way of arriving at the same result is to solve equation 16 directly for i considering q as a constant, thus:

$$i = \frac{q\left[Ri_0 + L\left(\frac{di}{dt}\right)_0\right] + Li_0}{L + qR + \frac{q^2}{C}} \tag{17}$$

The expression $\left(L + qR + \frac{q^2}{C}\right)^{-1}$ expanded by the binomial theorem would give the series just described. In other words, $\frac{1}{L + qR + \frac{q^2}{C}}$ is the sum of the series in question.

It is now necessary to interpret this operational equation. The true interpretation of course would be to apply the infinite series method just described. This, fortunately, is not necessary. The equation can be converted into the p form (methods for evaluating which are known) by the transformation $q = 1/p$ defined by equation 11. As was found, in the treatment following equation 11, the solution obtained from the p form of the operational equation is identical with that of the q form or more precisely with the infinite series form. Hence the p form may be reverted to again, keeping in mind that by doing so one merely is solving equation 11 by a more convenient method.

Setting $q = 1/p$ in equation 11,

$$i = \frac{\frac{1}{p}\left[Ri_0 + L\left(\frac{di}{dt}\right)_0\right] + Li_0}{L + \frac{1}{p}R + \frac{\left(\frac{1}{p}\right)^2}{C}}$$

$$i = \frac{p\left[Ri_0 + L\left(\frac{di}{dt}\right)_0\right] + p^2Li_0}{p^2L + pR + \frac{1}{C}} \tag{18}$$

But if equation 18 be rewritten in the form

$$\left(p^2L + pR + \frac{1}{C}\right)i = p\left[Ri_0 + L\left(\frac{di}{dt}\right)_0\right] + p^2Li_0 \tag{19}$$

an equation similar to equation 14 is obtained with 2 terms appended on the right of the equality sign. Note further that these appended terms all contain and vanish with the initial conditions. Here then is the form sought—a complete solution containing all the initial conditions, all in one operational equation. It is necessary only to solve this equation (19) in the usual manner (say, for example, by Heaviside's expansion theorem) to obtain the complete solution to the problem.

This last derivation is perfectly general and typical. Given any differential equation of the form

$$L\left(\frac{di}{dt}\right) + Ri + \frac{1}{C}\int i\,dt = E$$

it is necessary merely to convert it to the form

$$(a_1p^2 + b_1p + c_1)\,i = 0 \tag{20}$$

by differentiating to eliminate the integral sign, if it should occur in any term, and append on the right of the equality sign the terms

$$p\left[b_1i_0 + a_1\left(\frac{di}{dt}\right)_0\right] + p^2a_1i_0$$

and then solve the resulting operational equation by the usual methods. If any of the constants a_1, b_1, or

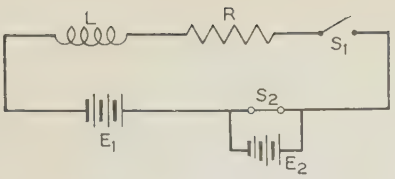

Fig. 3. A simple R-L circuit with 2 sources of electromotive force

c_1 happen to be zero, then so much the easier will be the solution.

If the original differential equation does not contain an integral term, the initial condition terms may be appended directly to the right-hand side of the equation. The presence of driving forces on the right-hand side of the equation offers no difficulty, and they remain as part of the equation. Care must be observed in appending the terms $p\left[b_1 i_0 + a\left(\frac{di}{dt}\right)_0\right] + p^2 a_1 i_0$ to choose the constants a_1, b_1, and c_1 correctly. In equation 20 these constants are defined as follows:

a_1 = coefficient of p^2 term
b_1 = coefficient of p term
c_1 = constant term

Thus, with an equation such as

$$L\frac{di}{dt} + Ri = E$$

there are 2 possibilities of procedure. Either it may be differentiated, obtaining

$$(p^2L + pR)\,i = 0$$

in which

$$a_1 = L \qquad b_1 = R \qquad c_1 = 0$$

or one may choose to work with the original form

$$(pL + R)\,i = E$$

since it does not contain any term with an integral sign. In this form the inital condition terms may be appended directly, but now

$$a_1 = 0 \qquad b_1 = L \qquad c_1 = R$$

In other words, to clarify the procedure remember that the equation

$$(a_1p^2 + b_1p + c_1)\,i = 0 \tag{20}$$

was solved by writing it in the form

$$(a_1p^2 + b_1p + c_1)\,i = p\left[b_1 i_1 + a_1\left(\frac{di}{dt}\right)_0\right] + p^2a_1i_0 \tag{21}$$

In a similar manner, the equation

$$L\frac{di}{dt} + R\,i = E$$

or

$$(Lp + R)\,i = E$$

may be written in the form

$$(pL + R)\,i = p\,(Li_0) + E$$

which becomes the new complete operational equation. For purposes of notation, equation 20 will be called the primary form, and 21 the subsidiary form.

In general, a given set of differential equations of the form (where $S = 1/C$):

$$\left.\begin{array}{l}
\left(L_{11}\frac{di_1}{dt} + R_{11}i_1 + S_{11}\int i_1dt\right) + \left(L_{12}\frac{di_2}{dt} + R_{12}i_2 + S_{12}\int i_2dt\right) + \ldots\ldots = f_1(t) \\
\left(L_{21}\frac{di_1}{dt} + R_{21}i_1 + S_{21}\int i_1dt\right) + \left(L_{22}\frac{di_2}{dt} + R_{22}i_2 + S_{22}\int i_2dt\right) + \ldots\ldots = f_2(t) \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
\left(L_{n1}\frac{di_1}{dt} + R_{n1}i_1 + S_{n1}\int i_1dt\right) + \ldots + \left(L_{nn}\frac{di_n}{dt} + R_{nn}i_n + S_{nn}\int i_ndt\right) = f_n(t)
\end{array}\right\} \tag{22}$$

which are the equations for the currents in an n-mesh network, are converted to the form:

$$\left.\begin{array}{l}
(a_{11}p^2 + b_{11}p + c_{11})\,i_1 + (a_{12}p^2 + b_{12}p + c_{12})i_2 + \ldots\ldots = f_1'(t) \\
(a_{21}p^2 + b_{21}p + c_{21})\,i_1 + \ldots\ldots\ldots\ldots\ldots\ldots = f_2'(t) \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
(a_{n1}p^2 + b_{n1}p + c_{n1})\,i_1 + \ldots\ldots + (a_{nn}p^2 + b_{nn}p + c_{nn})\,i_n = f_n'(t)
\end{array}\right\} \tag{23}$$

by differentiating. The initial condition terms:

$$\left.\begin{array}{l}
p\left[b_{11}i_{1_0} + a_{11}\left(\frac{di_1}{dt}\right)_0\right] + p^2a_{11}i_{1_0} + p\left[b_{12}i_{2_0} + a_{12}\left(\frac{di_2}{dt}\right)_0\right] + p^2a_{12}i_{2_0} + \ldots \\
\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
p\left[b_{n1}i_{1_0} + a_{n1}\left(\frac{di_1}{dt}\right)_0\right] + p^2a_{n1}i_{1_0} + p\left[b_{n2}i_{2_0} + a_{n2}\left(\frac{di_2}{dt}\right)_0\right] + p^2a_{n2}i_{2_0} + \ldots
\end{array}\right\} \tag{24}$$

then are appended to the right of the equality signs, and the resulting set of operational equations is solved in the usual manner to obtain the complete solution. Note that:

Equations 22 are the original differential equations.
Equations 23 are the primary equations.
Expressions 24 are the right-hand members of the subsidiary equations.

Example 1

Consider the circuit shown in figure 3. At $t = 0$ switch S_1 is closed; at $t = t_1$ switch S_2 is opened, introducing battery E_2 into the circuit. What is the equation of the current after $t = t_1$? The original differential equation will be

$$L\frac{di}{dt} + Ri = E_1 + E_2$$

Since it does not contain any term with an integral sign, it may be adopted immediately as the primary form.

$$(a_1p^2 + b_1p + c_1)\,i = E_1 + E_2$$

so that the subsidiary equation

$$(a_1p^2 + b_1p + c_1)i = E_1 + E_2 + p\left[b_1i_0 + a_1\left(\frac{di}{dt}\right)_0\right] + p^2a_1i_0$$

will be:

$$(Lp + R)i = E_1 + E_2 + p\,(Li_0)$$

since $a_1 = 0$; and

$$i = \frac{E_1 + E_2}{Lp + R} + \frac{p}{Lp + R} Li_0$$

$$i = \frac{E_1 + E_2}{R}\left(1 - \epsilon^{-\frac{Rt'}{L}}\right) + i_0\,\epsilon^{-\frac{Rt'}{L}}$$

where $t' = t - t_1$, and $i_0 = \frac{E_1}{R}\left(1 - \epsilon^{-\frac{Rt_1}{L}}\right)$, a constant.

Example 2

Capacitor C in figure 4, charged to a potential E_c, is discharged suddenly into the circuit. The constants of this circuit are of such values that $R = 2\sqrt{L/C}$. Find the equation of current. The ordinary differential equation will be:

$$L\frac{di}{dt} + Ri + \frac{1}{C}\int i\,dt = 0$$

Differentiating to convert it into the primary form:

$$\left(Lp^2 + Rp + \frac{1}{C}\right) i = 0$$

The subsidiary form is:

$$(a_1p^2 + b_1p + c_1)\, i = p\left[b_1i_0 + a_1\left(\frac{di}{dt}\right)_0\right] + p^2a_1i_0$$

or

$$\left(Lp^2 + Rp + \frac{1}{C}\right) i = p\left[Ri_0 + L\left(\frac{di}{dt}\right)_0\right] + p^2\,Li_0$$

At $t = 0$,

$$L\left(\frac{di}{dt}\right)_0 + Ri_0 + E_c = 0 \quad i_0 = 0$$

$$L\left(\frac{di}{dt}\right)_0 + Ri_0 = -E_c$$

Hence

$$\left(Lp^2 + Rp + \frac{1}{C}\right) i = p\left[-E_c\right]$$

$$i = \frac{-p}{Lp^2 + Rp + \frac{1}{C}} E_c$$

Applying the usual formulas,

$$i = -\frac{E_c}{L}\,t\,\epsilon^{-\frac{Rt}{2L}}$$

It is not necessary to memorize the subsidiary equation. Thus, consider again the differential equation for figure 4:

$$L\frac{di}{dt} + Ri + \frac{1}{C}\int i\,dt = 0$$

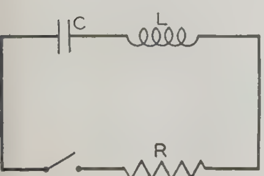

Fig. 4. A simple R-L-C circuit
$R = 2\sqrt{L/C}$

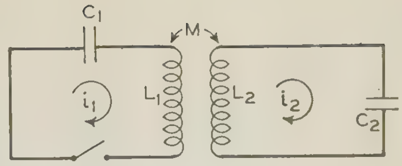

Fig. 5. A simple network comprising a mutual inductance and 2 capacitances

Differentiating,

$$L\frac{d^2i}{dt^2} + R\frac{di}{dt} + \frac{i}{C} = 0$$

Reintegrating, to bring in the initial conditions,

$$L\left[\frac{di}{dt} - \left(\frac{di}{dt}\right)_0\right] + R\,(i - i_0) + \frac{qi}{C} = 0$$

Rearranging,

$$L\frac{di}{dt} + Ri + \frac{qi}{C} = L\left(\frac{di}{dt}\right)_0 + Ri_0 = -E_c$$

Integrating once more,

$$L\,(i - i_0) + qRi + q^2\frac{i}{C} = -\,qE_c$$

$$\left(L + qR + \frac{q^2}{C}\right) i = -qE_c + Li_0$$

Substituting $q = \frac{1}{p}$ and $i_0 = 0$,

$$\left(p^2L + pR + \frac{1}{C}\right) i = -\,pE_c$$

$$i = \frac{-\,pE_c}{p^2L + pR + \frac{1}{C}}$$

as before.

Example 3

Capacitor C_1 in figure 5, charged to potential V, is discharged suddenly into the circuit shown. The original differential equations will be:

$$L_1\frac{di_1}{dt} + M\frac{di_2}{dt} + \frac{1}{C_1}\int i_1\,dt = 0$$

$$L_2\frac{di_2}{dt} + M\frac{di_1}{dt} + \frac{1}{C_2}\int i_2\,dt = 0$$

Differentiating to obtain the primary form,

$$\left(L_1p^2 + \frac{1}{C_1}\right) i_1 + Mp^2i_2 = 0$$

$$Mp^2i_1 + \left(L_2p^2 + \frac{1}{C_2}\right) i_2 = 0$$

The constants in the subsidiary equations will be:

$a_{11} = L_1$	$a_{12} = M$	$a_{21} = M$	$a_{22} = L_2$	$i_{1_0} = 0$
$b_{11} = 0$	$b_{12} = 0$	$b_{21} = 0$	$b_{22} = 0$	$i_{2_0} = 0$

Also when $t = 0$

$$L_1\left(\frac{di_1}{dt}\right)_0 + M\left(\frac{di_2}{dt}\right)_0 + V = 0$$

$$L_2\left(\frac{di_2}{dt}\right)_0 + M\left(\frac{di_1}{dt}\right)_0 = 0$$

Hence

$$\left(\frac{di_1}{dt}\right)_0 = \frac{-VL_2}{L_1L_2 - M^2} = k_1$$

$$\left(\frac{di_2}{dt}\right)_0 = \frac{V M}{L_1L_2 - M^2} = k_2$$

The subsidiary equations then become:

$$\left(L_1p^2 + \frac{1}{C_1}\right) i_1 + Mp^2 i_2 = L_1k_1p + Mk_2p = -pV$$

$$Mp^2 i_1 + \left(L_2p_2 + \frac{1}{C_2}\right) i_2 = Mk_1p + L_2k_2p = 0$$

If

$$L_1p^2 + \frac{1}{C_1} = l \qquad Mp^2 = m \qquad L_2p_2 + \frac{1}{C_2} = n$$

the subsidiary equations become:

$$l\, i_1 + mi_2 = -pV \qquad mi_1 + ni_2 = 0$$

so that

$$i_1 = \frac{-pV}{l - \dfrac{m^2}{n}} \qquad i_2 = -\frac{m}{n} i_1$$

to which the Heaviside expansion theorem may be applied to obtain the complete solution.

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2. Electric Circuit Theory and the Operational Calculus (a book), J. R. Carson.
3. Operational Methods in Mathematical Physics (a book), H. Jeffries.

Crossing the St. Lawrence With Unstressed Cable Lengths

In designing and building the 132 kv transmission line crossing between Kanawake and LaSalle, Quebec, on the St. Lawrence River, the unstressed cable lengths were calculated, measured, and cut to be continuous over 3 spans. The calculated unstressed lengths were measured in the field while the cable was being erected, without delaying the stringing and without necessitating rehandling of the cable.

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In 1931 the Cedars Rapids Manufacturing and Power Company, a subsidiary of the Montreal Light, Heat and Power Consolidated, completed the construction of a double-circuit 132-kv 30-mile steel-tower transmission line on the south shore of the St Lawrence River to tie in with the power development of the Beauharnois Power Company at Beauharnois, Quebec, and with the power plant of the Cedars Rapids Manufacturing and Power Company at Cedars, Quebec. The tie-in with Cedars was to supplement an already existing pair of lines on the north shore of the river. The importance of this line is evident from the fact that it ties in 2 of the main sources of supply with the City of Montreal.

In the route followed, the St. Lawrence River is crossed twice: first between Cedars and St. Timothee, Quebec; and second between Kanawake and LaSalle, Quebec. The Kanawake-LaSalle crossing is the longer, with a center span of 3,500 feet, approximately. At both these crossings the water flows very fast. At the Cedar-St. Timothee crossing there are the Cedars Rapids, and at the Kanawake-LaSalle crossing, the Lachine Rapids. This fast water necessarily involved a greater risk and cost in the erection of the cables at these crossings.

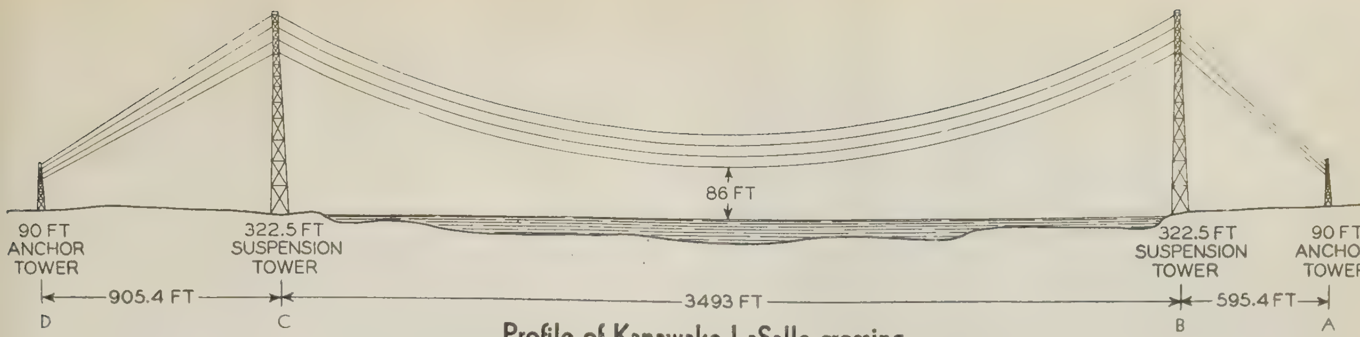
As the advantage of erecting the cables in one operation is quite evident under these conditions, namely, long span and fast water, it was decided, after careful study, to accomplish this by measuring the conductors to the calculated unstressed length in the field, cut them to this exact length, install the dead end equipment, and pull them into position thus completing the installation in one operation. As the cable was being erected it was pulled through a measuring trough 200 feet in length and measured. This operation involved no delay whatsoever since the pulling winch operated continuously.

It is believed that the calculation and cutting of the cables to an unstressed length in this particular case is unique in 2 ways: First, the cable is continuous over 3 spans, one long center span and 2 short adjacent spans; second, the cable was measured and cut to the calculated unstressed length in the field.

Sags and tensions were calculated as shown in the booklet "A.C.S.R. Graphic Method for Sag and Tension Calculations" by Theodore Varney.

The unstressed cable length for each particular

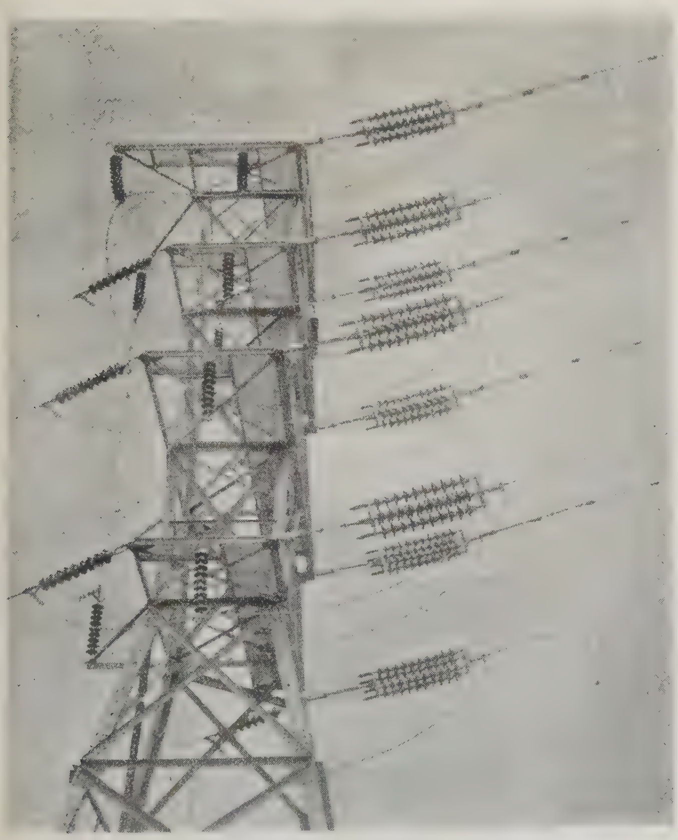
A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution. Manuscript submitted Sept. 10, 1934; released for publication July 15, 1935.



Profile of Kanawake-LaSalle crossing

condition was calculated for a temperature range from 0 to 70 degrees Fahrenheit, and a set of curves of unstressed length plotted against temperatures was made up and given to the field superintendent. These curves contained all the information that was required by the men in the field to enable them to cut the cable to the exact length.

The St. Lawrence River being one of the main arteries to the Atlantic, navigation regulations insist on a minimum clearance of 85 feet to the water line at all times. To obtain this clearance and have the heights of the main towers within reason, a high-strength steel-reinforced aluminum cable (A.C.S.R.) of 619,000 circular mils, having 42 aluminum and 19 steel strands, and an ultimate strength of 46,800 pounds, is used on the river crossing; instead of the 715,500 circular mil cable having 54 aluminum and 7 steel strands, and an ultimate strength of 25,000 pounds, which is used on the rest of the line.


Anchor tower at Kanawake end of crossing

As the procedures followed in the erection of the conductors and ground wires were identical for both crossings, this paper deals only with the Kanawake-LaSalle crossing in describing the erection of the conductors and the calculation of the unstressed cable lengths.

Details of Kanawake-LaSalle Crossing

Span (See Profile)	Horizontal Length Feet	Difference in Elevation (Feet)			
		Ground Wire	Top Conductor	Middle Conductor	Bottom Conductor
A-B	586.6	224.18	221.68	215.43	210.18
B-C	3,483.0	5.20	5.20	5.20	5.20
C-D	896.4	224.66	222.16	215.91	210.66

Conductors and Ground Wires

Type—Steel reinforced aluminum cable (A.C.S.R.)
Size—619,000 circular mils: 42 0.1214 inch aluminum strands; 19 0.1214 inch steel strands.
Ultimate strength—46,800 pounds.
Diameter—1.093 inches.
Total cross sectional area—0.704 square inch.
Weight per foot—1.334 pounds.
Number of conductors—6.
Number of ground wires—2.
Maximum loading condition—1/2 inch ice, 8 pounds wind at zero degrees Fahrenheit.
Maximum tension under above loading—23,400 pounds.
Resultant weight per foot of loaded conductor—2.697 pounds.

Erection of Conductors and Ground Wires

After the cable size had been selected and the towers and footing designs completed, the next problem was to string the first cable across the fast water. Various methods suggested themselves, the first being to carry the conductor across after the river froze over. But unfortunately, because of the extremely fast current, the water never completely freezes over at this point. Another method suggested was to carry over a light rope by means of a collapsible box kite. Because of the weight of line required to stretch across the river, 2 kites were hooked together. This idea might have worked except that the winds seldom were favorable.

After much searching and inquiring throughout the neighborhood, a man finally was found who knew the river rather well, and he contracted to take over the first line in a high powered motor boat.

It was realized that any rope that became waterlogged while being towed across the river would sink and create a tremendous drag which, in all probability, would defeat any attempt to get the line over

Cable measuring trough

by this means. To obviate this hazard a new $^1/_4$ inch manila rope was impregnated thoroughly by immersion in molten beeswax. One end of this treated rope was tied to the motor boat which then was started upstream across the river. While the rope was being pulled across it was observed to skip and jump over the surface of the water, creating practically no drag. This $^1/_4$ inch rope, as may be appreciated, was taken across successfully. The rope then was raised to the top crossarm of the suspension towers, passed through a set of travelers, and pulled clear of the water. A $^1/_2$ inch manila rope then was connected to the $^1/_4$ inch rope and pulled across the river, it in turn taking across a $^5/_{16}$-inch 6-strand (19 wires per strand) hemp-core steel cable, having a breaking strength of 9,000 pounds.

On the far side of the river was situated a power winch with a reel of $^9/_{16}$ inch steel cable having a breaking strength of 29,000 pounds. The $^5/_{16}$ inch cable was fastened to the $^9/_{16}$ inch cable and was pulled back across the river by means of a tractor, bringing the $^9/_{16}$ inch cable with it. This $^9/_{16}$ inch cable thereafter was used as the main pull-over cable for the conductors. At the same time as the $^9/_{16}$ inch cable was pulling across a conductor it was pulling across also the $^5/_{16}$ inch cable which always was left attached to the $^9/_{16}$ inch cable and used for pulling back this main pull-over cable to the starting position.

The reel of conductor to be strung over the river was situated between the anchor and suspension towers on the near side. As the conductor was unreeled it passed through a measuring trough, which had been laid out with a transit and level and marked in a 200 foot gauge length with a tested steel tape. From the measuring trough the conductor passed to a brake drum where it made 4 complete turns.

After the end of the conductor had been passed over the brake drum a compression dead-end connector was installed. The conductor was raised to the required crossarm point on the near suspension tower, passed through travelers and then connected to the $^9/_{16}$ inch pull-over cable. The power winch on the far side was started and the conductor gradually was pulled across the river, thence through travelers on the far suspension tower, and finally dead-ended on the far anchor tower.

The conductor was allowed to sag almost to the surface of the water so that when the brake was applied for short intervals when measuring the conductor it was not necessary to stop the power winch; the brake was applied for such short intervals that there was only a slight decrease in sag. One may note, therefore, that the measuring of the cable to the exact unstressed length took practically no extra time. When the final measurement had been made, the brake was applied, the power winch stopped, and the cable snubbed off at the near suspension tower with 2 come-alongs and an equalizer.

The cable was cut, the dead-end connector compressed on, and the cable then taken off the brake drum; the complete dead-end assembly, including the turnbuckle connected to the upper yoke, was made on the ground and connected to the conductor. A $^3/_4$ inch steel cable was connected to the upper yoke and passed through travelers fastened to the required crossarm point on the near anchor tower. The conductor and dead-end assembly then were pulled into position by means of a heavy tractor. One thus may note that the final pulling in was done with the $^3/_4$ inch steel cable and tractor. This completed the initial installation of the conductor; all that remained to be done was to adjust the turnbuckles to give the proper sag and tie in the conductor at the 2 suspension towers.

The erection of the ground wires was somewhat different as the 2 ground wires also are dead-ended at the suspension towers and, therefore, offered a more difficult problem. The procedure for the first few stages however, was identical with that for the conductors. One readily may appreciate that because of the ground wires' being dead-ended at each suspension tower and also because of the large sag that was kept in the cable as it was being pulled across the river, the unstressed length would not be sufficient to reach between the 2 points of support on suspension towers until the cable was in its final position. It was necessary, therefore, to allow the near end of the cable to pass beyond the near suspension tower in order to permit tying in at the far suspension tower.

The erection of the ground wire was accomplished in the following manner: The cable was pulled through the measuring trough, passed around the brake drum, and the dead-end connector compressed on. The $^9/_{16}$ inch pull-over cable was connected to the dead-end connector and the ground wire pulled across the river in the same manner as were the conductors. When the required unstressed length of ground wire had been measured it was snubbed

Brake drum for stopping cable during the short intervals required for measuring

off at the near suspension tower, as previously mentioned, and the compression dead-end connector installed. A 3/4 inch steel cable was connected to this to check the tension, and the come-alongs were removed. The erection was continued, and when this end of the ground wire had reached the travelers on the near tower it again was snubbed off with the come-alongs as before. The 3/4 inch steel cable then was removed and the dead-end assembly, which was suspended at the crossarm point on the near suspension tower, was connected to the ground wire. The 3/4 inch steel cable then was connected to the upper yoke, and the whole assembly was allowed to go along with the ground wire far enough to permit hooking into the dead-end assembly at the far suspension tower. The tension in the 9/16 inch pull-over cable gradually was released, thus throwing the strain on the insulators on the far suspension tower. The near end then was pulled back by means of the 3/4 inch steel cable and tractor and was fastened to the near suspension tower, thus completing the installation.

The ground wires on the 2 end spans were the first cables erected; then the ground wires on the center span were installed, thus providing a back guy for the suspension towers in case of any undue strain when erecting the conductors.

The ground wires on the 2 end spans also were cut to the calculated unstressed length, and as their erection was done over land, the installation of these cables was a relatively simple matter.

To keep the tension in the conductors and ground wires as low as possible when pulling into position, the turnbuckle on each of the dead-end assemblies was left in the extended position. The unstressed length had been calculated for the turnbuckles in the neutral position, and when this position was obtained it was found that for all practical purposes the sag checked exactly with the required value.

It is of interest to note that since these crossings have been in service they have been subjected to temperatures as low as 40 degrees below zero, Fahrenheit, and at other times ice loadings of 5 pounds per foot of conductor have occurred without damage.

To add a certain amount of flexibility in the sagging of the cables, a turnbuckle with a 9 inch adjustment was added at each dead-end point. These turnbuckles were used in the final adjustment of the sag to the values shown on the sag and tension charts.

Because −20 degrees Fahrenheit with no ice or wind is a more severe loading condition for the ground wire on the short spans than on the long spans, the limiting maximum condition was set at 18,000 pounds tension at −20 degrees Fahrenheit in the plane of the resultant at the upper point of support for the ground wire in the 2 outer spans. This change was taken care of by a slight adjustment of the turnbuckle.

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 42 pages appears all remaining unpublished discussion of papers presented at the 1935 A.I.E.E. summer convention, Ithaca, N. Y., June 24–28. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for publication in a subsequent issue. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

D-C Braking of Induction Motors

Discussion and authors' closure of a paper by F. E. Harrell and W. R. Hough published in the May 1935 issue, pages 488–93, and presented for oral discussion at the applications to iron and steel production session of the summer convention, Ithaca, N. Y., June 27, 1935.

P. C. Smith (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper gives some interesting test data on d-c braking of induction motors but it does not clearly distinguish the squirrel cage type from the wound rotor, and the conclusion might be drawn that the 2 have the same braking characteristics. Such is not the case. Plugging a squirrel cage motor of normal rotor resistance results in comparatively low braking torque because, as pointed out in the paper, it is working on that part of the speed torque curve between 100 and 200 per cent slip where the torque, as the result of fixed secondary resistance, is normally low. With a wound rotor motor, additional resistance can be connected in the secondary and the peak braking torque can be made approximately equal to the maximum or pull-out torque of the motor. A normal motor would have a pull-out torque of from $2^1/_4$ to $2^1/_2$ times full load torque which means that high braking torques may be obtained with plugging on a wound rotor motor. Extremely high d-c excitation would be required to produce an equal torque with d-c braking.

Tests were made recently on a 200 horsepower 10-pole 60-cycle wound rotor motor. With external secondary resistance to give full load torque at the beginning of the braking cycle, the rotor was brought to rest by plugging in approximately one second. Approximately 8 times normal d-c excitation, that is, 8 times the direct current required to produce normal flux, and the most favorable secondary resistance were required to equal this stopping time with d-c

braking. Note that the plugging test was made with secondary resistance to give only full load torque at the beginning of the cycle. By suitable adjustment of secondary resistance, the maximum plugging torque could have been increased approximately to pull-out torque, thus reducing the stopping time.

This paper also states that for the stopping time likely to be required, saturation can be neglected and that double excitation will give 4 times the torque. This is true only when a machine is operated at very low induction. If the braking torque desired means going up to several times normal excitation, the torque increase may be considerably less than the square of the excitation. There is also real danger in increasing the excitation to very high values. The unbalanced magnetic pull, tending to pull the stator and rotor together, varies as the square of the flux and in large machines the flux and hence the excitation is limited by this factor. In other words, the torque obtainable with d-c braking may be limited by unbalanced magnetic pull.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The authors in their paper express the desirability of making available a method for calculating speed-torque curves, currents, and so forth. I published such a method in the *Elektrotechnik und Maschinenbau*, Vienna, October 2, 1910, but in view of the remoteness of this article both in time and location, it is not surprising that the authors were not familiar with it.

In reviewing this article, I find that it is quite complete and accurate, except that it neglects the reactive drop in the secondary. This was quite permissible because the motors then under consideration were of the wound secondary type with secondary resistance, and therefore the secondary reactance was of no great practical importance in the results obtained. In squirrel cage motors, however, the secondary reactance is not negligible under some operating conditions. A method taking this into account is shown in the diagram in figure 1 of this discussion.

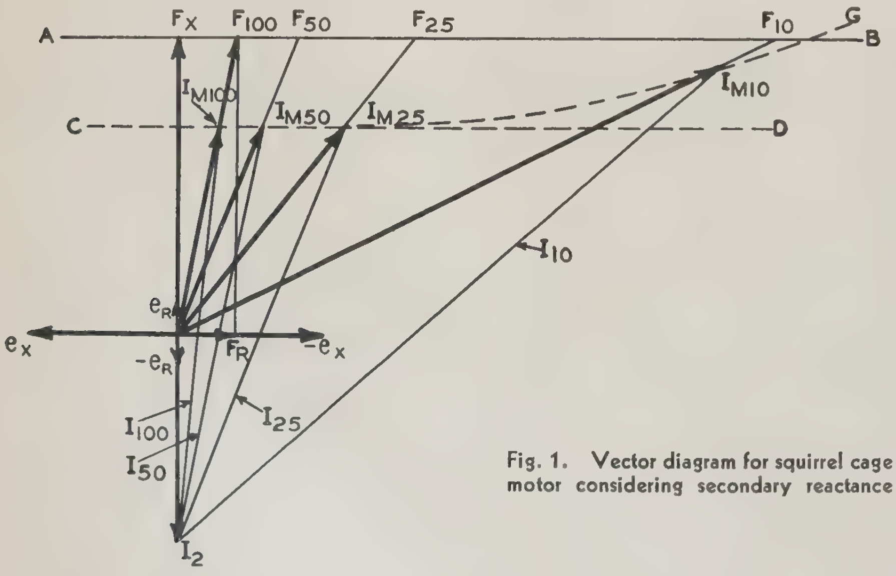


Fig. 1. Vector diagram for squirrel cage motor considering secondary reactance

If we assume that there is a secondary current I_2 while the rotor is rotating in the d-c field, such current of course causes the usual reactance drop e_x and a resistance drop e_r. Accordingly, voltages $-e_x$ and $-e_r$ must be induced in the motor, and this in turn means that the fields F_x and F_r leading these voltages by 90 degrees must be available. The resultant field is the geometric sum of the 2 fields (indicated as F_{100}). If the vectors so far discussed correspond to the synchronous speed, i. e., full frequency in the rotor, corresponding fields for other speeds can be derived readily. The reactance drop in the rotor decreases in proportion to the speed and frequency. However, since the field inducing the voltage $-e_x$ changes its frequency in the same proportion, the size of the field F_x required for the assumed secondary current will remain constant for all speeds. The ohmic drop voltage e_r and the corresponding voltage $-e_r$ remain constant, but in so far as this voltage is induced at half frequency, at 50 per cent speed it requires a field twice as large as for full frequency and we obtain the resultant field vector F_{50}. Similarly, at quarter speed, the ohmic drop field must be 4 times as large as at full speed; at 10 per cent speed, it must be 10 times as large, with resultant field vectors of F_{25}, F_{10}, etc. With the resultant fields known, the resultant magnetizing currents required to set up such fields can be found from the saturation curve; these are indicated in the figure as vectors I_{M100}, I_{M50}, I_{M25}, I_{M10}. The primary currents, I_{100}, I_{50}, I_{25}, and I_{10}, follow from the vectorial combination of the secondary current and the magnetizing currents as shown. The primary currents thus obtained are equivalent alternating currents, from which, however, the corresponding d-c values can be determined readily for various stator connections as outlined in the article previously referred to.

By working out the diagram of figure 1 for a number of secondary current values, a family of curves as shown in figure 2 of this discussion can be obtained, and it is then possible to obtain values for assumed primary currents such as MN or OP. The corresponding torque values follow directly from the product of the secondary current and the resistance component of the field applying to each point.

While the method indicated is simple in principle, it requires the calculation of a great many individual values. This, however, is unavoidable in cases where the change in the saturation of the machine cannot be neglected. While in an induction motor operated from an a-c source, the total field remains reasonably constant, thereby simplifying calculations, the field in a motor excited by means of direct current varies over wide ranges unless it is continuously readjusted, which is usually impracticable. If, for the purpose of simplification, we neglect the secondary reactance, the current proportions for a given direct current I_1 are indicated in figure 3 of this discussion. With the assumption made the magnetizing current I_M is always at right angles to the secondary current, which means that point B travels along the circle $ABCD$. The proportions shown for point B are somewhat in line with normal motor operation and I_M' is a measure of the field strength. As the motor slows down, however, and approaches zero speed, proportions somewhat as indicated at point C may be obtained. It will be seen that the magnetizing current I_M', and therefore the field, is very much larger. Unless readjustments are made this will result in very excessive magnetic pulls, which in turn are likely to

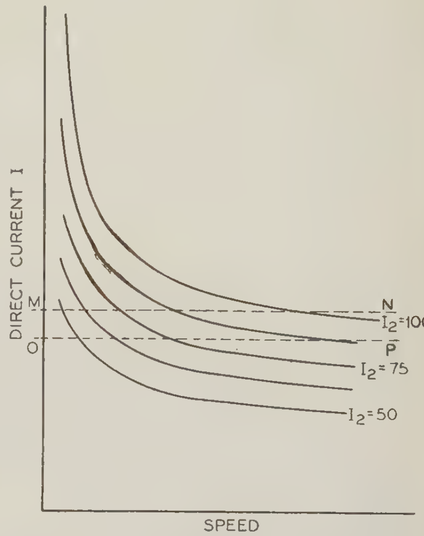


Fig. 2. Curves plotted from method of figure 1

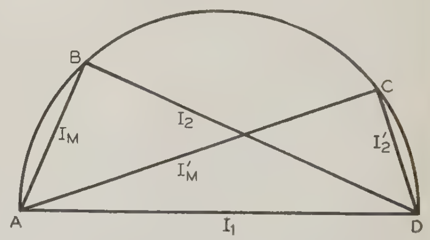


Fig. 3. Current proportions for d-c excitation

lead to mechanical troubles if the mechanical design of the motor is made without this condition in mind. These magnetic pulls are large not only on account of the large field, but also because certain equalizing currents which are set up while the motor is running at normal alternating voltages are absent.

Figure 4 shows how in the article previously referred to the deceleration of a motor has been calculated. Curve *A* represents the speed-torque curve of the motor; *B*, the load and friction resistance. Curve *C* is the sum of these. By approximating this latter curve by 3 straight lines, *D*, *E*, and *F*, equations for such straight lines can be set up and formulas for the deceleration have been derived as applying to these straight lines.

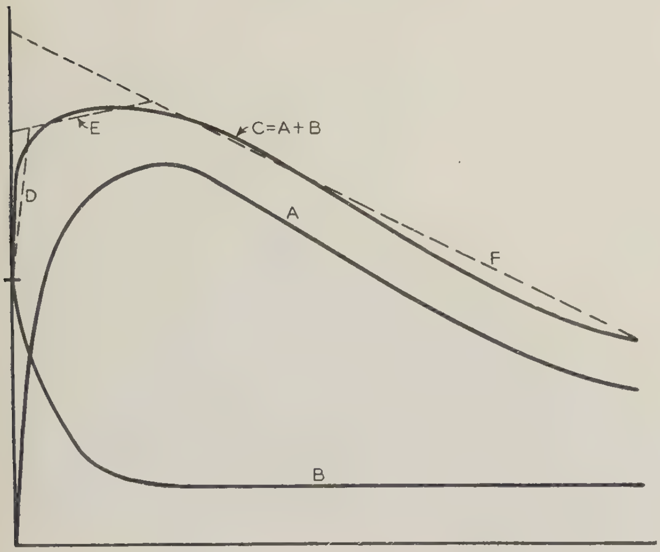


Fig. 4. Method of calculating deceleration of motor

The discussion given by P. C. Smith and other comparisons made are likely to result in the impression that there is a fundamental difference between the torque obtainable with d-c braking and that obtainable with a-c plugging. Any differences which might exist are not so much of a theoretical fundamental nature as they are of practical consequence. The torques that can be obtained with the 2 methods are exactly the same so long as there is sufficient possibility of regulating both the stator and rotor circuit conditions, as is the case with wound-secondary motors. The torque is always proportional to the secondary current and the resistance component of the field regardless of whether the field is induced by alternating or direct current. However, as already pointed out, the field in a-c operation is reasonably constant, making the regulation of the secondary current conditions reasonably simple. On the contrary, with d-c excitation both the fields and currents tend to vary over wide ranges, as indicated in figure 3, and therefore in order to obtain the most desirable conditions, adjustments in both the primary and the secondary circuits are required to maintain the proper relations between the 2 circuits; this is likely to lead to complications in some practical applications, particularly where the load may vary. Nevertheless, certain other cases will be found in actual practice, such as the one described by the authors for small squirrel cage motors, where d-c braking is advantageous if proper precautions are taken with regard to both the electrical and the mechanical design of the motors.

L. A. Umansky (General Electric Co., Schenectady, N. Y.): This paper is a very excellent one and gives a clear picture of application of d-c dynamic braking to induction motors. It is certain that both the designing and the application engineers will use this article widely as a reference.

The comments which are given below are made primarily from the viewpoint of an application man. While it is well known that d-c dynamic braking, as described by the authors, is appreciably better than plugging, it is felt that dynamic braking can be applied in yet another and more efficient manner, affording a still greater advantage from the standpoint of motor losses and motor heating.

It is assumed that a group of squirrel cage motors driving a mill table or coiler is furnished with power from a separate adjustable frequency set. The latter consists of an alternator driven by a d-c motor. The frequency of the a-c system is controlled by the excitation of the d-c motor. Assume, for instance, that the frequency range is, say, 20–60 cycles, giving a 3:1 speed range to the mill table.

If a squirrel cage motor connected to an inertia load is started at the frequency and voltage at which it will operate when fully accelerated, then the rotor losses are approximately equal to the kinetic energy which is put into the rotating masses during the accelerating period. Stator losses add their share to the motor heating.

Likewise, when d-c excitation is applied to a squirrel cage motor when it is still running at its full speed (i. e., immediately after it has been disconnected from its source of operating frequency and voltage), then the stored energy of the rotating parts is converted into heat in the rotor, (neglecting the friction losses). Exciting direct current also contributes its share to the motor heating.

Now let us consider another method of operation. Assume that a group of squirrel cage motors with an operating range of 20–60 cycles must be accelerated from standstill to its maximum, or 60 cycle, speed. The adjustable-frequency motor-generator set is idling at 20 cycles. The squirrel cage motors are connected to the alternator and are accelerated to the 20 cycle speed. Since the energy of the rotating parts at 20 cycles is only $^1/_9$ of that at 60 cycles, the rotor losses are reduced in the ratio 9:1. After the 20 cycle speed is reached, the motor generator set is accelerated, together with the squirrel cage motors.

Of course, motor losses occur while accelerating in this manner from 20 to 60 cycles, but such losses are very much lower than if the motors were started at 60 cycles with 100 per cent slip.

When these motors are to be brought to rest from their 60 cycle speed, they remain connected to the alternator, and the set is rapidly decelerated to the 20 cycle speed. The squirrel cage motors act as induction generators, pumping the stored energy of rotating parts into an external resistor which is then connected to the terminals of the alternator. The stored energy of the motor generator set is partly spent as heat in the resistor and is partly pumped back into the d-c system.

Finally, when the 20 cycle speed is reached, the squirrel cage motors are disconnected from their a-c supply and d-c dynamic braking is applied. This brings the motors to rest. The rotor losses, during the dynamic braking period, are approximately $^1/_9$ of the corresponding losses if d-c braking were applied at 60 cycles.

It is evident that with this method of control, if all details are properly worked out, the rates of acceleration and retardation of the mill table or coiler can be readily made as fast as with the method described in the paper. The torque of the squirrel cage motors may be easily maintained at a high value by alternator field forcing. The motor generator set can be retarded as fast as, or faster than, the table motors; both the alternator and the d-c motor are used for braking, and the only inertia involved is that of the electrical machines themselves. In contrast, the squirrel cage motors are connected to mechanical parts having large inertias of their own.

Calculations show that with the operating method suggested in this discussion, the total losses in the squirrel cage motors may be reduced as much as 50 per cent, as compared with the method described in the paper. Either the motors will run much cooler and operate more reliably, or else smaller motors can be selected, reducing the first cost of the equipment. Several installations of this type are in successful service, or on order.

There is another factor that should be taken into account when discussing the rates of acceleration and retardation of a mill table. After all it is not the movements of the table itself, but of the metal on the table that we are interested in. The only force connecting the metal to the table is the friction. The coefficient of friction is seldom, if ever, higher than 0.2–0.25. Thus, rates of acceleration or retardation higher than, say, $0.25 \times 32.2 = 8.05$ feet per second per second, are not practicable, since then the metal will merely slip on

rollers and its surface easily might be scratched. On this basis a strip traveling at, say, 2,000 feet per minute, or 33 feet per second, cannot be stopped in less than approximately 4 seconds, even though the table itself can be stopped quicker. In these 4 seconds the strip will travel approximately 66 feet, even if the rate of retardation is uniform; otherwise the distance traveled will be still greater.

F. E. Harrell and **W. R. Hough:** Referring to P. C. Smith's comment, it would appear likely to the authors that too high a value of secondary resistance was selected as "the most favorable" in the test of d-c braking the 200-horsepower wound rotor motor. With the most favorable secondary resistance, the time to stop by direct as opposed to alternating current is likely to predicate a curve with much less than full load torque at the beginning of the cycle.

With reference to his further statement, the authors would cite that by test on motors carrying windings capable of developing their full open rating as motors, in no case did the value of braking direct current equal or exceed the alternating current incident to plugging the motor to rest in an equal time.

The authors are deeply grateful to R. E. Hellmund for citing his contribution on this subject in the Vienna paper of 1910, and shall be interested particularly in comparing their test results with his theoretical approach.

The comments offered by L. A. Umansky are very timely with regard to the runout table application. With regard to the 2 methods of acceleration and deceleration described by him, the authors agree to the principle that the losses in the motors are lessened by acceleration to a low base frequency and then speeding up by acceleration of the d-c motor driving the alternator set as compared to acceleration directly to the final frequency, although they are not in agreement as to the 50 per cent reduction proposed. The authors find it necessary to differ with him in his assertion that rates of acceleration and retardation can be readily made as fast with one method as the other. Theoretically, this should be possible, but as a practical matter it seems improbable that a 500-horsepower, 3:1 field weakening motor should be called upon to accelerate from full to weak field speed with a 200 per cent or greater load in one second elapsed time.

In the authors' estimation, both methods have their definite fields of application. Where the duty cycle to be imposed makes necessary acceleration to speeds of 1,600–2,000 feet per minute of all or portions of a runout table in 4 seconds or less, then acceleration to a final frequency seems unavoidable. If longer times are acceptable, then the economy of acceleration through the alternator set should be applicable. Similarly, if stopping in 5 seconds or more is acceptable, then deceleration through the alternator set should be applicable, but if shorter stopping times are necessary for any reason, then d-c braking seems the most practicable.

After all, most such installations of either type in modern strip mills are hardly recognizable by their conceptors after the operating people have introduced their own modifications in duty cycle and method of operation. The basic difference between the 2 methods, as outlined by Umansky, seemed to the authors to be the time element.

Electric Power Equipment for Steel Plants

Discussion and author's closure of a paper by R. H. Wright published in the May 1935 issue, pages 481–5, and presented for oral discussion at the applications to iron and steel production session of the summer convention, Ithaca, N. Y., June 27, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Little can be added to the author's review of the past developments in electrical power equipment for the steel industry, as his paper is concise and yet as complete as possible with the time and space available for such papers. It may, however, be appropriate to briefly discuss future possibilities, particularly with reference to the applicability of the newest member in the family of electric devices—namely, electronic devices—to the steel industry.

Undoubtedly there will be many instances where electronic devices will be used for controlling, regulating, and metering purposes as the industry becomes more familiar with the possibilities along this line. A few installations of this kind have already been made. However, the introduction of electronic devices for main power purposes has been delayed because the mercury arc rectifier, which is the only electronic device able to handle large currents in practice, did not compare favorably from an efficiency point of view with other converting apparatus for continuous voltages generally applied in steel mill work. Improvement in this situation has been brought about through the development of the igniter type of mercury rectifier which materially increases the efficiency for lower voltages as compared with the ordinary rectifier. In view of this and also because pool-type rectifiers have reached a high degree of reliability, their entrance into the steel industry for conversion purposes is to be expected as soon as plant expansions are undertaken. Inasmuch as these devices do not require any attendants and are especially favorable from an efficiency point of view where the load factor is low, they should prove attractive in quite a number of cases.

While electronic devices as a means for obtaining economical speed control of motors have been discussed quite frequently, the prospects of their practical application are not particularly bright at this time. Most of the proposed arrangements are at present not economical either from a first-cost or an operating point of view. The arrangement coming closest to a practical solution is a voltage-controlled pool-type rectifier for adjustable-speed d-c motors that are not called upon to regenerate. Unfortunately, however, there is usually a need for quick speed reduction where adjustable-speed d-c motors are used, which in turn is likely to require temporary regenerative operation. The pool-type rectifier is not reversible in its operation, which means either a reconnection for regenerative operation, resulting in undue complications, or else a second pool-type device to handle the regenerative current; this, however, appreciably increases the first cost. In some cases where the regenerative periods are very short and where, therefore, the return of such regenerative power to the line is of no practical importance, arrangements might be made for dissipating such power in a rheostat.

It is not altogether impossible that the latter arrangement may work out advantageously in the not-too-distant future, but on the whole it is not to be expected that electronic devices will be used to any marked extent for motor control in steel mills within the next few years.

R. H. Wright: R. E. Hellmund's comment on the status of the mercury arc rectifier answers questions frequently raised by steel mill engineers. In the past, 0.8 power factor synchronous motor generators have been used almost entirely for direct current supply, because of their ruggedness and simplicity and because they afforded a means of regulating the power factor of the plant system. Now that power factor correction is no longer a major consideration in the selection of new equipment, the mercury arc rectifier has a number of features which are attractive to steel plant engineers. This condition, together with a growing faith in electronic devices generally, will cause any future developments to be received favorably by steel mill operating men.

D-C Circuit Breakers for Steel Mill Service

Discussion of a paper by William Deans published in the June 1935 issue, pages 594–8, and presented for oral discussion at the applications to iron and steel production session of the summer convention, Ithaca, N. Y., June 27, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author's comments on the secondary and arcing contacts through which the current is led in such a manner that the contact pressure is increased by the magnetic action of the current were rather interesting to me. The necessity for this became quite evident to us about 8 years ago when we first had laboratory facilities available giving 80,000 amperes at full voltage. At that time it was found that in automatic substations for rather high power concentration the ordiary industrial contactors did not have sufficient interrupting capacity, while the conventional carbon breakers then available were not quite suitable from a mechanical point of view for the frequent operation of these substations. This led to the development of certain circuit interrupters in which the secondary and arcing contacts were first formed in the conventional manner but which, after a number of tests, were built along the principles described in the paper. As a matter of course, the experience was

utilized in all subsequent designs wherever considered necessary. The same tests also indicated that with these enormous currents and the high rate of rise, the self-inductance of the current path to the secondary and arcing contacts is of some consequence, and therefore an inductive voltage has to be overcome in the transfer of current from the main to the secondary contact, which will lead to harmful arcing at the main contact unless all possible efforts are made to reduce the length of the path from the main to the secondary contacts.

The tripping feature shown in the paper which is obtained by splitting one of the conductors and making one part thereof self-inductive by surrounding iron, was used in the early high-speed breakers for railway substations and was found to be of material assistance in preventing flashover of the rotary converters.

In view of the fact that flashover of machines is one of the most likely causes of short circuits, the availability of electronic devices as an additional means for protection and bringing about high speed circuit breaker operation may be of some significance. With the 80,000 ampere testing equipment previously mentioned, light sensitive tubes are arranged near the brushes and cause the breakers to trip if there is any flashing at the brushes. However, since these particular machines were designed for frequent short-circuit service, flashing has not occurred. In some of the laboratories for short-circuit testing, light sensitive tubes have also been applied in the neighborhood of the busses and have at times operated and given the desired protection, when arcing occurred in the bus structure or a switching device not intended for heavy arcing service.

C. H. Black (nonmember; General Electric Co., Philadelphia, Pa.): The author is to be congratulated upon the timely subject matter and excellent presentation of his paper. Two arrangements of the switching equipment are possible. One is based upon the use of 2-pole air-circuit breakers for generator and motor protection, while the other makes use of single pole breakers.

With the first arrangement, as illustrated in the paper, the 2 main busses are seldom, if ever, spaced very far apart. In fact, there would be no point in so doing, because the solid bar connections from those busses must be brought close together when they are brought to the terminals of the 2 pole breakers. The author has referred to the enormous mechanical stresses, at time of short circuit, to which the busses are subjected in such an arrangement. It is, of course, obvious that the connections to the breakers and the conducting members of the breakers themselves may be subjected to even greater stresses because the spacings here are usually less than the bus spacing and, unfortunately, the means available for mechanical support of these members are not always so dependable as, for example, the very sturdy bus-supporting structure which Deans describes. Then, too, there is the ever present possibility of that most dreaded of all electrical failures—a bus short circuit. Such short circuits have arisen from widely varied causes, ranging from human carelessness to flashovers following emission of gases from circuit interrupting devices. In this connection, it should be remembered that the 2 closely spaced upper studs of each 2 pole circuit breaker are solidly connected to the 2 busses of opposite polarity and therefore are, in effect, a part of the bus. The metallic enclosure unquestionably provides a pleasing appearance and may tend to minimize the hazard of carelessness which would otherwise be a serious obstacle to any wide spread adoption of this arrangement. Unfortunately, however, it does not eliminate other possible sources of bus short circuit and it so greatly increases the cost of the equipment that, for these among other reasons, the idea of metal enclosures and drawout breakers has not yet gained recognition or acceptance for any other installations, including even the several installations where the 2 breaker arrangement has been used.

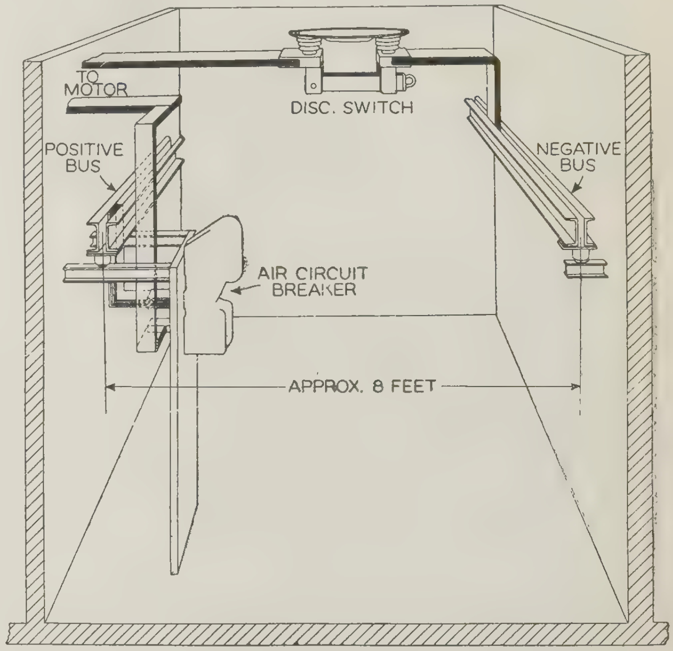


Fig. 1. Typical 600 volt machine arrangement, showing breaker and bus arrangement

The other arrangement is based upon the use of single pole breakers. Starting from the leads of each generator, which are usually rather widely spread, the connections and the busses of opposite polarity are spaced just so far apart as the building space allocated to switchgear will permit. A distance of from 6 to 8 feet between centers of busses or connections of opposite polarity is not uncommon.

The arrangement generally used is shown schematically in figure 1 of this discussion. The improbability of bus short circuits is obvious. It can also be seen that short-circuit stresses, which vary inversely as the square of the separation, are minimized and that no conductors of opposite polarity are located within the region where gases might be liberated from the interrupting device. Hence, from the viewpoint of eliminating bus short circuits and of safely withstanding short circuits which may occur elsewhere, this arrangement would seem highly advantageous. A single-pole circuit interrupting device is shown in one lead of the typical machine with a knife switch (for isolating purposes only) in the other lead. This requires the use of an interrupting device which was developed some years ago for this specific service, and which has been successfully used in a large number of 600 volt mill installations, including a narrow strip and a merchant mill in the Detroit area. Based upon the highly successful operation with the single pole interrupter and the resultant separation of busses in one of these installations in the Detroit area, the engineering layout for a new strip mill in this same location specifies a similar arrangement and similar interrupters. In this new installation the concentration of power will be as great as in any thus far encountered either in existing installations or in any mills now contemplated.

The interrupter referred to has a specially designed magnetic blow-out coil and arc chute, with design verified by factory tests and by field experience. Designed specifically for steel mill service, provision is made for reducing maintenance to a minimum and for permitting the device to withstand safely the numerous overloads to which it may be subjected. Solid-silver high-pressure block contacts and a compact, yet extremely sturdy, self-contained operating mechanism are the salient characteristics which guard against deterioration as a result of frequent operation and heavy overloading. A rate-of-rise tripping device, which does not at any time reduce the effective cross section of the copper conductors, has been included in the construction of this device throughout the last 8 or 9 years. Deans has very clearly stated the advantages accruing from the use of such a means of tripping.

It might be mentioned that the single-pole breaker arrangement has been used for many years not only in steel mills but also in 600 volt railway service, so that there can be no question of the adequacy of a suitably designed single-pole breaker installation; however, the use of only one single-pole interrupter is not absolutely essential to the arrangement described. Obviously, conventional types of air circuit breakers, with or without the modifications described by Deans, can be used by having the 2 poles

(necessary for interrupting duty) made up of 2 single-pole units, one to be used in the location I have indicated for the circuit interrupter, and the other to replace the knife switch. Such an arrangement may be used when the extra expense involved is warranted.

Speed Transients of D-C Rolling Mill Motors

Authors' discussion and closure of a paper published in the April 1935 issue, pages 387–94, and presented for oral discussion at the applications to iron and steel production session of the summer convention, Ithaca, N. Y., June 27, 1935.

L. A. Umansky and **T. M. Linville:** We wish to make 2 clarifying statements:

1. The oscillogram, on the basis of which curves *A* and *B* of figure 2 of the paper were plotted, was obtained by the engineers of a steel company and given to the authors for the purpose of studying the case and of recommending the most suitable drive. Curve *C* of the same figure was calculated by the authors. Not wishing to disclose the steel company's name, the authors did not acknowledge the origin of the oscillogram; at the same time they do not wish to claim any credit for having obtained it experimentally.
2. A statement made by the authors regarding the scrap resulting from the speed fluctuations of electric motors individually driving the stands of a tandem mill may be misinterpreted. The authors certainly did not mean to imply that the tube mill to which reference is made, rolls its product with a higher percentage scrap than any other mill not arranged or equipped in the same manner. Quite to the contrary, the authors believe that the use of individual drives for the tandem mill stands results in an arrangement which is not only practicable and successful, but is usually the most economical and flexible one. It goes without saying that the electric drives for such a mill should be designed with proper characteristics, and the authors hope that their paper serves as a further contribution to that end.

Design and Operation of Huntley Station No. 2

Author's closing discussion of a paper published in the June 1935 issue, pages 632–45, and presented for oral discussion at the power generation session of the summer convention, Ithaca, N. Y., June 25, 1935. Other discussion was published in the September 1935 issue, pages 996–1001.

H. M. Cushing: Referring to the split bus system at Huntley, C. M. Gilt states that the Brooklyn Edison Company is able usually to keep the voltage variation between busses to less than 2 volts. The very fact that the subtransmission system with its 4 kv substations and low voltage network vaults is practically a network in itself precludes any appreciable unbalance between the 22 kv busses with the scheme of connections used, that is, with the feeders equally divided between the 2 busses. On rare occasions there has been a slight phase angle between the busses which was evident by the slight reversal of the watt-hour meter on one of the 22 kv station feeders supplying the 550 volt reserve bus (the two 22-kv station feeders tie the station busses together through the 550 volt reserve bus, which is usually lightly loaded), indicating a very small flow of power from one bus to the other. The maximum voltage difference which has been observed at Huntley No. 2 between the 2 22-kv busses has been 1.5 volts on 120 volt basis. This has been easily corrected by interchanging one or 2 22-kv feeders. No trouble has been experienced at any time with unequal loading or voltage difference between the 2 busses, nor has any trouble been experienced with undesired network switch operation, or by unequal loading or overloading of network transformers.

M. Penn mentions the low turbine availability factor. This was caused in part by the fact that inspections and repairs were made on a 40 hour week basis. Had the turbine been required by the load, 2 shifts and overtime would have reduced the outages (the result of ordinary causes) to less than half the value given. The unusual cause for outages was an unstable shaft forging, as explained by A. R. Smith in his discussion.

The 2 19-foot steel stacks superimposed on the building steel are gunite lined and no corrosion is evident to date. Difficulty is now being experienced in finding a suitable protective coating for the inside of that portion of the unlined accordion type steel breechings which extend above the roof. Any new breeching will probably be lined with gunite, with special provision for thermal expansion.

In table I of the paper the idle but available 1933 hours for unit 1, should be interchanged with the corresponding 1932 figures for unit 2.

As M. Penn states, the split bus scheme of operation does require care in the system layout so that the split is not nullified by the ties through the transmission system. At present the kilovoltamperes that would be fed into a bus fault through the subtransmission system from the unfaulted bus are approximately 100,000. In the paper it was stated that a bus fault under present conditions would amount to 640,000 kva; however, the 100,000 kva would increase the figure to 740,000 kva. In clearing a bus fault at Huntley No. 2, it is apparent from the diagram that a breaker interrupts only a part of the total, because the fault current is divided over a number of circuits.

F. A. Allner suggests the rehabilitation of the 25 cycle plant as a means of obtaining 60 cycle power. This could not be considered at the time Huntley No. 2 was designed because all of the capacity of Huntley No. 1 was in use and the commitments to the 25 cycle customers required more power than would be released by the 60 cycle conversion.

The steam conditions are as Allner states, 425 pounds per square inch gauge pressure, and 750 degrees Fahrenheit total temperature at the turbine throttle. Coal burned is a high volatile (27 to 34 per cent) Pittsburgh district bituminous coal, running from 8 to 12 per cent ash, and 2 to 4 per cent sulphur. The weighted average of the heating values of coal as burned has been:

1931	13,030 Btu
1932	12,815 "
1933	13,135 "
1934	13,183 "

The reason why Huntley Station is kept in running reserve during periods of high flow when its capacity is not needed to carry the load is that the 60 cycle hydro power is transmitted to Buffalo over 200 miles of transmission lines supplying other loads enroute.

A boiler held in hot reserve can be brought on the line in less than 10 minutes from the time it is called for. A cold boiler requires 90 minutes, using 4 15-minute periods of firing and 3 10-minute intervals during which the fire is out. This is necessary to prevent excessive metal temperatures on the interdeck superheaters. For the first 15 minute period the oil lighters are kept lit continuously. After that, the lighters are used only for starting the powdered coal. Each lighting of the pulverized fuel burners is listed in table II as a separate boiler start, hence putting on the line from cold requires 4 starts. The fuel to keep a boiler hot for 24 hours cost $16.00, and to bring a cold boiler on the line it cost $26.00.

It is the author's opinion that higher steam pressures and binary cycles should be seriously considered in a base load design. As for Huntley No. 2, the extra cost of a higher pressure plant could not be justified now, nor when the plant was built.

The author, in mentioning the advantage to be gained by designing the steam plant and Buffalo's 60 cycle delivery system concurrently, had in mind mainly the electrical features of the plant. The coincident design permitted the fullest advantage to be realized in the adoption of the split bus scheme. Allner is right if he is referring in his discussion to the choice of steam and mechanical details.

F. R. Longley's inquiry regarding the magnitude of a bus short if split winding transformers were not used can best be answered by assuming all of the ultimate generators and transformers referred to in the paper connected to one bus without reactors, in which case the fault kilovoltamperes would be in excess of 3,000,000. Interlocks to prevent closing the 2 breakers on the same circuit simultaneously, which would tie the two busses together, were omitted purposely to permit transferring a circuit between the busses without interruption.

The cable faults which burned themselves clear when the neutral was grounded solidly occurred in the splices where the clearance from conductor to ground is greater than in the cable itself. Although the power flowing into the fault was severe enough to burn off the conductor and melt the lead sheath, the fault cleared itself and left the live conductor exposed. It is estimated that the magnitude of the current from the power house end was 10,000 amperes, and from the other end 1,000 amperes. The cable is 3 conductor, sector type, shielded (except the splices) $^{20}/_{64}$ inch paper, $^{9}/_{64}$ inch lead, operating with 22,000 volts between conductors. Grounding of the system neutral through a 5 ohm resist-

ance has not resulted in any trouble with overvoltages when there are single line to ground faults, nor has any low frequency induction been experienced by the communication companies.

E. G. Bailey calls attention to the "snow balling" which takes place when powdered coal is stored. This snow balling reduces the effectiveness of fine pulverization. It is obvious that the fineness of the coal as fired and not its fineness as pulverized determines the thermal efficiency of combustion. This disadvantage of the bin system was not stated in the paper. Bailey points out that many improvements in the design of boiler house equipment have been effected since Huntley No. 2 was built, and mentions the controversy between the advocates of the bin and direct fired systems when pulverized coal was first adopted for Huntley Station No. 1. The trend at that time was so strong for the bin system that the manufacturer made 3 attempts to influence the adoption of the bin system.

H. C. Albrecht questions the possible disadvantage of concentrating so much steam generation at one point. The electric machines can be as far apart electrically when located in the same station as if they were located physically miles apart. Outgoing cables are routed through different duct lines and different streets to preserve their isolation. The superior circulating water conditions and the relatively small amount of subtransmission will probably result in adding considerably more capacity to this site. The 25 cycle system will continue to supply large industrial loads on the Niagara Frontier. Sixty cycles will be used for domestic, commercial, and some industrial applications.

The generator autotransformers are located in line with the line transformers shown in figure 2 of the paper.

Separately driven exciters were chosen because exciter trouble would not then affect the availability factor of the main unit and because the unit can be shut down more quickly in case of mechanical trouble in the turbine by continued application of full field.

It is planned to provide an aisle in the electric bay for handling the field of future machines by means of specially designed dollies; one to operate on the armature laminations, and one on the floor. The field of the 200,000 kva tandem turbogenerator with its shaft, but without direct driven exciter, will be 82 feet long.

In contrast to Albrecht's statement that it is more economical to supply auxiliary motors of over 25 horse power at 2,200 volts, our studies indicate that motors of 300 horsepower can be supplied more economically at 550 volts than at 2,200 volts. Although circuit breakers are used between the generator leads and the house service transformers, these may be omitted if one is willing to risk a transformer fault shutting down the generator.

D. F. Pennell's statement, that if a tandem compound turbine with its better heat rate cannot be justified economically then neither can 4 stage feed water heating, is correct as a general conclusion. However, for Huntley Station, full credit could not be given to the tandem machine for the smaller boilers and boiler room that would be theoretically possible and the proper debit allowed the transaction for the theoretically larger turbine room required. Provisions to accommodate still larger turbines in the future had already established the width of the turbine room, and it is doubtful if the slightly smaller boiler room equipment would have been purchased even though the tandem machine had been selected.

Contrary to R. A. Hentz's opinion, we have found large indoor installations of the type of switchgear in question superior to the outdoor type in performance, maintenance, and capital cost. Our experience with both indoor and outdoor installations, together with a thorough analysis of all of the types of practical switchgear available at the time that Huntley No. 2 was built, favored the indoor type. Mr. Hentz refers to the slight damage caused by the opening of a disconnecting switch under load in one of their outdoor installations as a demonstration of the superiority of outdoor over indoor installations. Huntley No. 2 was placed in operation before the interlocks and "mark-up" were effective. A switch was opened under load, and the resulting fault was cleared so quickly by the instantaneous operation of the bus differential relays that no damage resulted and service was resumed immediately on the bus.

F. W. Gay suggests combining the generator and line transformers into a single bank with incremental capacity between the tertiary and the 22 kv busses, and the omission of any 22 kv breakers. In our judgment, this scheme would require the same equivalent transformer capacity as used, and the 22 kv breakers could not be omitted conveniently; furthermore, tap changers are required between the 22 kv busses and the 110 kv system to permit proper control of the voltages. All of this probably would result in such large and complicated transformers as to be impractical, as well as in the disadvantage of having too much of the station capacity in a single unit.

S. M. Dean raises the question of duplicate busses and switchgear. Duplicate busses infers an operating bus and a spare bus. It is evident from Huntley No. 2 layout that, although the busses are physical duplicates, they are not operated as duplicates except for maintenance purposes. Each of the 4 bus sections is a fundamental part of the operating diagram and is used continuously; however, the circuit breakers are in duplicate for the following reasons:

1. Maintenance is made convenient and, therefore, adequate.

2. All of the circuits may be kept in operation practically all of the time irrespective of the maintenance requirements on the bus or switchgear.

3. Any other scheme of connections would have required a larger number of bus sections and bus section breakers because of the necessity of dividing the feeders into a large number of small groups so that only a few of them would be out of service at one time. These additional breakers and the increased amount of bus work would have gone far to cancel any saving obtained by the omission of the duplicate breakers. A scheme using a larger number of busses also would have made it more difficult to obtain load division between the busses and transfer of load along the busses, especially with only one generator in operation, which is very often the case.

4. In our experience no other scheme of connections has approached the double bus scheme from the standpoint of operating convenience.

In reply to C. A. Powel's question regarding measures to control load divisions with the system frequency regulated from the Hell Gate Station, it may be stated that this is being done by biasing the frequency control at Hell Gate with tie line load control in parallel with the Niagara-Hudson system, on which there are 3 hydro stations and one steam station operating with the Warren system of frequency control.

H. L. Wallau states that, had a multidrum type of boiler been selected, a considerably higher rate of load pickup would have been feasible. It is interesting to note in this connection that the majority of the peak load standby plants use straight tube boilers. It was probably a matter of judgment rather than figures that induced the Buffalo General Electric Company to put in a spare boiler. It has the advantage that, when all are used for full station load, the maintenance on furnaces, fans, etc., will be lower.

The 1933 figures appear twice in table II. Their inclusion twice in Wallau's summaries has led to an erroneous conclusion. Then, too, many of the available hours for the third boiler antedate the installation of No. 2 turbine.

The author considers a bleeder steam cycle, whether using 2, 3, or 4 points of bleeding, as a simple cycle to operate, thus meeting design requirement No. 1 of the paper, in contrast to the reheat steam cycle which requires extreme operating care to protect the metal of the reheater at times of sudden load changes.

The author believes that in comparing boiler plant investment costs Wallau has used figures not entirely comparable. The item of 12.1 per cent given in the original paper for coal handling equipment is, with small additions, sufficient to supply more than 1,000,000 kw of capacity either by rail or by water. In most stations only one of the 2 methods of delivery is provided for. Equipment for 175,000 tons storage is also included. The comparison should be made omitting coal handling equipment but including coal preparation equipment.

In comparing the heat rate of Huntley No. 2 for 7 months' operation with the 12 months' operation heat rate of the steam station referred to by Wallau, it should be noted that the Huntley figure was for the period of the year when the circulating water temperature was the highest. The Huntley turbines are loaded more at this season of the year because of reduced stream flows at the water power plants. The maximum output on the 3 50,000 kw machines probably came during the season of coldest circulating water. In addition, these machines have more condenser surface per kilowatt of capacity than the Huntley turbines as shown in the following table:

Number and size of turbines	3 50,000 kw	2 80,000 kw
Condenser surface, square feet	57,000	45,000
Condenser surface per kilowatt, square feet	1.14	0.563
Circulating water per condenser, gallons per minute	70,000	80,000
Current per kilowatt of capacity, gallons per minute	1.4	1.0

These large condensers are not economically justifiable for Huntley No. 2.

Transient Voltages in Rotating Machines

Discussion and author's closure of a paper by E. M. Hunter published in the June 1935 issue, pages 599–603, and presented for oral discussion at the electrical machinery session of the summer convention, Ithaca, N. Y., June 27, 1935.

L. V. Bewley (General Electric Co., Pittsfield, Mass.): The author uses an equation for the effective capacitance of the coils in a slot which is based on the assumption of a uniformly distributed series and shunt capacitance circuit with zero capacitance from the last turn to the bottom of the slot. Actually, the circuit consists of a finite number of lumped-constant sections, and it is worth while to see how closely the approximate formula checks.

For an n turn slot (see figure 1 of this discussion) the current and voltage of the kth turn ($k > 1$) from the top are

$$i_k = \left\{ \frac{-(C+C')\sinh(n-k)\omega + C'\sinh(n-k-1)\omega}{\sinh(n-2)\omega - (1 + C/K + C'/K)\sinh(n-1)\omega} \right\} E$$

$$e_k = \left\{ \frac{(1 - C'/K)\sinh(n-k)\omega - \sinh(n-k+1)\omega}{\sinh(n-2)\omega - (1 + C/K + C'/K)\sinh(n-1)\omega} \right\} E$$

where

$$\cosh\omega = (1 + \frac{\omega^2}{2!} + \frac{\omega^4}{4!} + \ldots) = 1 + \frac{1}{2}\left(\frac{C}{K}\right)$$

and if $(C/K) < 1$, then approximately

$$\omega \cong \sqrt{C/K}$$

The effective capacitance is

$$C_{\text{eff.}} = C + \frac{i_1}{E} =$$

$$K\left[\frac{C}{K} + \frac{(C'/K)\sinh(n-2)\omega - (C/K + C'/K)\sinh(n-1)\omega}{\sinh(n-2)\omega - (1 + C/K + C'/K)\sinh(n-1)\omega}\right]$$

For example, if $C'/K = 0.20$, $C/K = 0.10$, and $n = 6$, then $\omega = 0.316$ and

$$C_{\text{eff.}} = K$$

$$\left[0.10 + \frac{0.20 \sinh 1.26 - 0.3 \sinh 1.58}{\sinh 1.26 - 1.3 \sinh 1.58}\right]$$

$$= 0.367\,K$$

For this case the approximate formula would give

$$\sqrt{CK} = K\sqrt{\frac{K}{C}} = K\sqrt{0.10} = 0.316\,K$$

which is sufficiently good agreement.

The solution of the circuit shown in figure 7 of the paper is of some interest, in that an initial static state can be specified in terms of traveling waves and then these waves used for calculating the transient following the closing of the switch to the unexcited generator.

Referring to figure 2 of this discussion, there is shown a transmission line of surge impedance Z at an instantaneous voltage E and carrying an instantaneous current I. Let us consider the possibility of representing this situation by 2 pairs of traveling waves moving in opposite directions:

$$E = f_1(x - vt) + f_2(x + vt) \quad (1)$$

$$I = \frac{f_1(x - vt)}{Z} - \frac{f_2(x + vt)}{Z} \quad (2)$$

Therefore

$$f_1 = \frac{1}{2}(E + ZI) \quad (3)$$

$$f_2 = \frac{1}{2}(E - ZI) \quad (4)$$

and thus the instantaneous steady state condition is replaceable by traveling waves f_1 and f_2.

Now let switch S be closed on an impedance $Z(p)$. The part of f_1 to the right of S moves away while the part to the left may now be regarded as an infinite rectangular wave meeting a transition point impedance consisting of Z and $Z(p)$ in parallel. Likewise, that part of f_2 to the right of S is an infinite rectangular wave striking Z and $Z(p)$ in parallel. The resultant voltage at S therefore is

$$e = \frac{2Z(p)}{2Z(p) + Z}(f_1 + f_2) = \frac{2Z(p)}{2Z(p) + Z}$$

$$E = \frac{2Z(p)}{Z(p) + Z/2}\,\frac{E}{2} \quad (5)$$

This equation shows that the situation is equivalent to a wave $E/2$ striking $Z(p)$ from a surge impedance $Z/2$ (the lines to the right and left of Z are in parallel). The load current I cancels out and is therefore immaterial.

Before the switch is closed, the endless waves f_1 and f_2 may be considered as reflections of each other at the 2 ends of the line. In particular, if the line is not carrying a load, equations 3 and 4 show that the 2 waves are equal in magnitude and in sign, and in effect we have the reflections from an open-end line.

Let this concept be applied to the circuit shown in figure 3 of this discussion, where Z_2 is the surge impedance of the generator, C the protective capacitor, and Z_1 the surge impedance of the connecting line (or bus) of length T. It is assumed that the length of the generator windings in microseconds is long compared with that of the bus, so that we can neglect reflections from the generator neutrals, for the purpose of this analysis.

At the transition points 1 and 2 the reflection and refraction operators are

$$a' = \frac{\beta - p}{\alpha + p} = \text{reflection operator for waves approaching along } Z_2$$

$$b' = \frac{\alpha + \beta}{\alpha + p} = \text{refraction operator for waves approaching along } Z_2$$

$$a = -\frac{\beta + p}{\alpha + p} = \text{reflection operator for waves approaching along } Z_1$$

$$b = \frac{\alpha - \beta}{\alpha + p} = \text{refraction operator for waves approaching along } Z_1$$

where

$$\alpha = \frac{Z_1 + Z_2}{Z_1 Z_2 C} \text{ and } \beta = \frac{Z_1 - Z_2}{Z_1 Z_2 C}$$

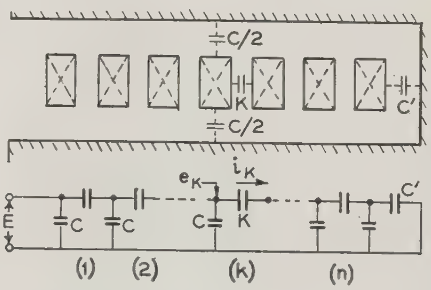


Fig. 1 (above). Diagram representing slot with n turns

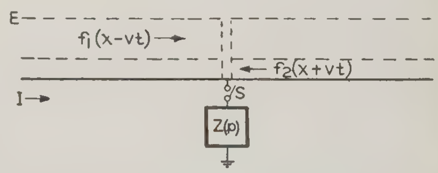


Fig. 2. Representation of instantaneous steady state conditions by traveling waves

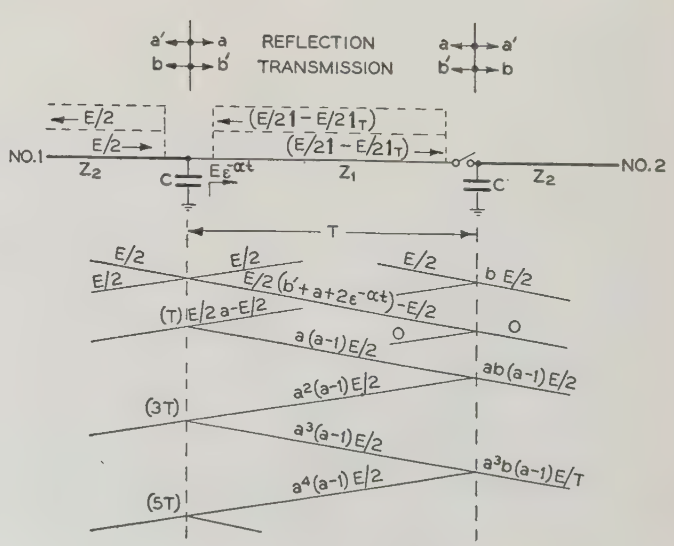


Fig. 3 (right). Analysis of traveling waves in generator circuit

Before switch S is closed, generator 1 is excited to E volts and we have

$$e_1 = b' \frac{E}{2} + b \frac{E}{2} + E\epsilon^{-\alpha t} = \frac{E}{2}\left(\frac{\alpha + \beta}{\alpha + p} + \frac{\alpha - \beta}{\alpha + p} + \frac{2p}{\alpha + p}\right) = E$$

where the first term is the voltage due to wave $E/2$ approaching from the left, the second term is due to wave $E/2$ approaching from the right, and the third term is the voltage due to the discharge of capacitor C through Z_1 and Z_2 in parallel. These terms add up to E as they should. It is seen that the waves $E/2$ are charging the capacitor at the same rate at which it is discharging, so that its voltage remains constant. At the other end $E/2$ approaching from the left reflects from an open end and yields a total voltage E.

When switch S is closed the wave $E/2$ moving to the right along Z_1 then encounters the impedance of C and Z_2 in parallel and at that instant we recognize the presence of 4 waves:

$E/2$ moving to the left on Z_2 of 1
$E/2$ moving to the right on Z_2 of 1
Finite wave $E/2\ (1 - 1_T)$ moving to the right on Z_1
Finite wave $E/2\ (1 - 1_T)$ moving to the left on Z_1

The successive reflections are then completed with the help of the lattice shown in figure 3 of this discussion, where each finite wave on Z_1 is considered as the superposition of 2 infinite waves of opposite sign displaced by T microseconds, and the capacitor discharge wave is given separate entity. The initial wave group leaving e_1 is completely cancelled by the $-E/2$ part of the finite wave on Z_1 moving to the right,

$$\frac{E}{2}\left(b' + a + 2\epsilon^{-\alpha t}\right) - \frac{E}{2} =$$

$$\frac{E}{2}\left(\frac{\alpha + \beta}{\alpha + p} - \frac{\beta + p}{\alpha + p} + \frac{2p}{\alpha + p}\right) - \frac{E}{2} = 0$$

The remainder of the lattice is clear. The voltage built up at e_2 due to these successive reflections then is

$$e_2 = \frac{E}{2}\left\{b + [ab(a-1)]_{2T} + [ab(a-1)]_{4T} + \ldots. + [a^{(2n-1)}\, b(a-1)]_{2nT} + \ldots.\right\} \quad (6)$$

The general term is

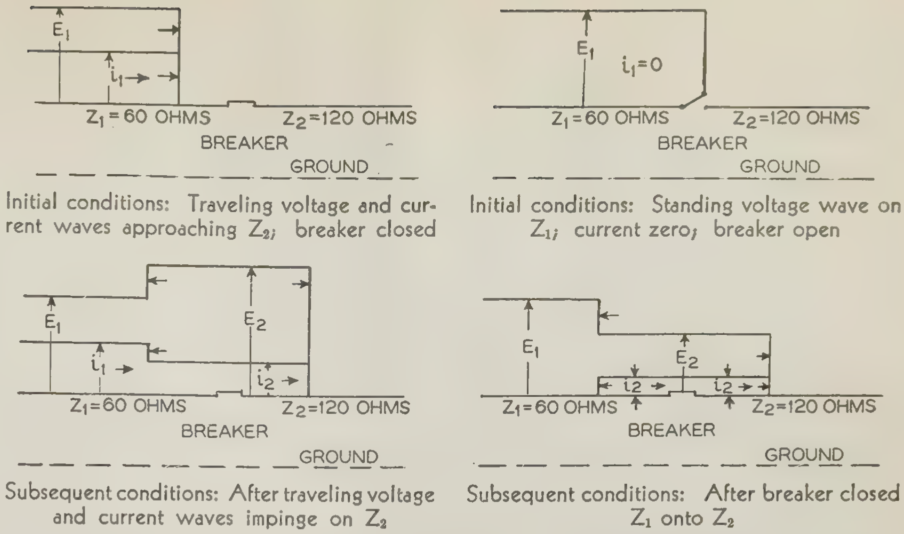
$$\frac{E}{2}\,[a^{(2n-1)}\, b(a-1)] = \frac{E}{2}(\alpha - \beta)\left[\frac{(p+\beta)^{2n}}{(p+\alpha)^{2n+1}} + \frac{(p+\beta)^{2n-1}}{(p+\alpha)^{2n}}\right] =$$

$$\frac{E}{2}\left\{\frac{\alpha^2 - \beta^2}{\alpha\beta}\left(\frac{\beta}{\alpha}\right)^{2n}(1 - \epsilon^{-\alpha t}) + \frac{\alpha - \beta}{\beta}\,\epsilon^{-\alpha t}\sum_{k=1}^{2n}\left[-\left(\frac{\beta}{\alpha}\right)^{k}\frac{(\beta t)^{2n+1-k}}{(2n+1-k)!} + \right.\right.$$

$$\left.\frac{(2n)!}{k(2n-k)!}\sum_{r=1}^{k}\frac{(\beta t)^{2n+1-r}}{(k-r)!\,(2n+1-r)!\,(r-1)!}\left(-\frac{\alpha}{\beta}\right)^{k-r}\right] +$$

$$\frac{\alpha - \beta}{\beta}\,\epsilon^{-\alpha t}\sum_{k=1}^{2n-1}\left[-\left(\frac{\beta}{\alpha}\right)^{k}\frac{(\beta t)^{2n-k}}{(2n-k)!} + \frac{2n-1}{k(2n-k-1)!}\right.$$

$$\left.\left.\sum_{r=1}^{k}\frac{(\beta t)^{2n-r}}{(k-r)!(2n-r)!(r-1)!}\left(-\frac{\alpha}{\beta}\right)^{k-r}\right]\right\} \quad (7)$$



Initial conditions: Traveling voltage and current waves approaching Z_2; breaker closed

Initial conditions: Standing voltage wave on Z_1; current zero; breaker open

Subsequent conditions: After traveling voltage and current waves impinge on Z_2

Subsequent conditions: After breaker closed Z_1 onto Z_2

Fig. 4. Comparison of the phenomena of traveling waves (left) and of standing waves (right)

J. F. Calvert (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): During the past 2 years I have made a study of the dielectric strength of the turn insulation of armature windings. The impulse ratio for new turn insulation appears to be about 1.2 to 1.5. Turn insulation will stand far more voltage stress than is imposed on it by the normal generated voltage—so much more in fact that it is not reasonable to use this as a measure of the strength or requirement of turn insulation on a 13,000 volt machine. The amount of turn insulation used has been determined by years of field experience as the amount necessary to prevent failures. These failures, when they occurred, probably resulted from lightning surges or switching surges in nearby parts of the system.

Fielder and I have made studies of the voltage distributions in the windings of rotating machines resulting from lightning surges and from switching surges. There is a fundamental difference in these phenomena which does not seem to be brought out very clearly in this paper. In a lightning surge the voltage arrives as a traveling wave, while in a switching surge it is drawn out of a standing wave on the charged side of the breaker. The following simple case will illustrate this difference. Assume 2 lines with surge impedances Z_1 and Z_2 connected by a breaker. If the breaker is already closed when a traveling wave E_1 reaches Z_2, then the resulting voltage E_2 is

$$E_2 = \frac{2Z_2}{Z_1 + Z_2}E_1 \quad (1)$$

Thus, E_2 may be either greater or less than E_1. If the line Z_1 is charged to a voltage E_1, and the breaker then closed onto Z_2, we find that now

$$E_2 = \frac{Z_2}{Z_1 + Z_2}E_1 \quad (2)$$

which is always less than E_1. (For an illustration of these cases, see figure 4 of this discussion.) This shows immediately how important the external circuit constants are in switching surge phenomena. Suppose Z_2 represents a machine with a surge impedance of 500 ohms. If Z_1 represents an overhead line of 500 ohms surge impedance, then for the switching surge E_2 is exactly half E_1. But if Z_1 represents the surge impedance of 6 60 ohm cables, in parallel, then $E_2 = \frac{500}{500 + 60/6}E_1 = 0.98E_1$. This is a practical example from a recent investigation. In actual practice the voltage wave will be sloped off somewhat because the capacitance of the uncharged side of the breaker must be fed through the incoming line. Also, the impedance offered by the machine is not a constant, but varies appreciably with time.

Of course, changes in concepts as new data are obtained are fully justified. Nevertheless, it is of interest to note that in the paper by Rudge, Wieseman, and Lewis, and their closing discussion (reference 3 of Hunter's paper) 600 to 1,050 ohms was expected to cover the range of surge impedances for rotating machines. Hunter now shows a value of 120 ohms. We have obtained values on one machine which varied with time from about 180 to 250 and on another which varied with time from about 600 to 1,800 ohms. Of course, it has been well recognized for some time that the total surge impedance of a machine is decreased

by paralleling more parts of the windings, much as is any other simple impedance because the electrostatic coupling between windings is small and the electromagnetic coupling is not large. For details see the appendix of reference 6 of Hunter's paper. I might state, however, that the impedance as a function of time was determined at the terminals of the generator by means of cathode ray oscillograph measurements. A noninductive resistance was used in the circuit. From readings to ground and across the resistance, the impedance was calculated. The steepness of the applied wave was relatively unimportant. I wish to reiterate the claim made a year or 2 ago, that there are not enough data on machine surge impedances available at this time to permit one to make generalizations concerning their range of values, because the surge impedance of any one winding is still unpredictable.

When the rate of rise of voltage at the machine terminals is known, Hunter's paper suggests that the resulting voltage between turns be calculated by considering the simple capacitance coupling between turns and between turns and ground. However, the manner proposed for doing this assumes at the start no net charge on the turns other than the lead turn. As the lead turn goes into the coil only one way while the other turns of the coil go 2 ways from the point where the current enters the coil, there must be current as well as voltage induced in the inner turns of the lead coil. I have fully treated this in an earlier paper (reference 6 of Hunter's paper) where the results are given in convenient curve form. The gain in accuracy may be small, but it takes care of features neglected by Hunter, and being in curve form is at least as easy to use.

I am unable to agree with solutions 1, 3, and 4 of Hunter's figure 7, and submit here my solutions for the same circuits.

Assume the breaker to be closed when a voltage E_1 exists on Z_1. This is the equivalent of suddenly applying a voltage $E_1 = E_a\mathbf{1}$ across the breaker in the direction Z_1 toward Z_2. This can be broken into 2 components E' and E''. (See figure 5 of this discussion.)

$$E' = iZ_1 \tag{3}$$

$$E'' = \frac{iZ_2}{1 + Z_2cp} \tag{4}$$

$$E' + E'' = E_a\mathbf{1} \tag{5}$$

where p = the differential operator $\frac{d}{dt}$, and $\mathbf{1}$ = the Heaviside unit function symbol. From this,

$$\frac{E''}{E_a} = \frac{1}{Z_1c} \cdot \frac{1}{\frac{Z_1 + Z_2}{Z_1Z_2c} + p}\mathbf{1} \tag{6}$$

$$= \frac{Z_2}{Z_1 + Z_2}\left[1 - \epsilon^{-\frac{Z_1 + Z_2}{Z_1Z_2c}t}\right] \tag{7}$$

Letting $Z_1 = 60$, $Z_2 = 120$, and $c = 0.37 \times 10^{-6}$,

$$\frac{E''}{E_a} = 0.667\left[1 - \epsilon^{(-0.0675 \times 10^6 t)}\right] \tag{8}$$

which is nearly a straight line up to $t = 1.0 \times 10^{-6}$ seconds.

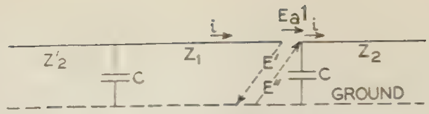


Fig. 5. Resolution of voltage into 2 components

$$\left.\frac{d(E''/E_a)}{dt}\right|_{t=0} = 0.045 \times 10^6 \tag{10}$$

Let E_{rl} be the reflected wave back along Z_1.

$$E_{r1} = -E_a + E_a[(0.667)\{1 - \epsilon^{-(0.0675 \times 10^6 t)}\}] \tag{11}$$

For one microsecond

$$E_{r1} \cong -E_a \tag{12}$$

At the end of 0.1×10^{-6} seconds, E_{rl} reaches the left end of Z_1.

Let E_2' be the resulting voltage on Z_2' and E_{r2} be the reflected voltage to the right on Z_1.

$$-E_a + E_{r2} = E_2 \tag{13}$$

$$c\frac{dE_2'}{dt} + \frac{E_2'}{Z_2'} = \frac{(-E_a - E_{r2})}{Z_1} \tag{14}$$

from which

$$E_2' = \frac{-E_a2Z_2}{Z_1 + Z_2}\left[1 - \epsilon^{-\frac{(Z_1 + Z_2)}{Z_1Z_2c}t}\right] \tag{15}$$

At the end of one microsecond

$$E_2' = -0.087E_a \tag{16}$$

so again approximating, we write

$$E_{r2} \cong +E_a \tag{17}$$

When this reaches the right end of Z_1 a new component on Z_2 arises, which is

$$E_2 = \frac{E_a\,2Z_2}{Z_1 + Z_2}\left[1 - \epsilon^{-\frac{(Z_1 + Z_2)}{Z_1Z_2c}t}\right] \tag{18}$$

for which

$$\left.\frac{d\left(\frac{E_2}{E_a}\right)}{dt}\right|_{t=0} = 0.090 \times 10^6 \tag{19}$$

where t is measured from the instant of this second impact at the right hand end of Z_1. Assuming all such reflections to produce straight line rises at the right hand end of Z_1, then at the end of one microsecond the total voltage here is

$$E_2 = \left\{\begin{array}{l} 0.045 \times 10^6 \times 1.0 \times 10^{-6} \\ +0.0900 \times 10^6(0.8 + 0.6 \\ +0.4 + 0.2)10^{-6} \end{array}\right\} E_a \tag{20}$$

$$= 0.2250E_a \tag{21}$$

This is about half Hunter's value for curve 1 at t = one microsecond. Actually $E_2 < 0.2250\ E_a$. It appears that curves 1 and 3 of Hunter's figure 7 should be interchanged. Curve 2 agrees with the above calculations. One may proceed in a similar manner for curve 4 by replacing Z_1 by $L = 0.0172 \times 10^{-3}$, and keeping all other symbols the same.

Then

$$E' = \frac{i(Z_2 + Lp + LZ_2cp^2)}{1 + Z_2cp} \tag{22}$$

$$E'' = \frac{iZ_2}{1 + Z_2cp} \tag{23}$$

$$E' + E'' = E_a\mathbf{1} \tag{24}$$

Then,

$$E'' = \frac{E_a}{LC}\,\frac{1}{(p + \alpha)^2 + \omega^2}\mathbf{1} \tag{25}$$

where

$$\alpha = \frac{1}{2Z_2c} \qquad \omega = \sqrt{\frac{2}{LC} - \frac{1}{4Z_2^2C^2}}$$

From which

$$E'' = \frac{E_a}{LC}\left[\frac{1}{\omega^2 + \alpha^2}\right]\left[1 - \epsilon^{-\alpha t}(\cos \omega t + \frac{\alpha}{\omega}\sin \omega t)\right] \tag{26}$$

or

$$E'' = \frac{E_a}{2}\left[1 - \epsilon^{-\alpha t}(\cos \omega t + \frac{\alpha}{\omega}\sin \omega t)\right] \tag{27}$$

Let $Z_2 = 120$, $L = 0.0172 \times 10^{-3}$, and $C = 0.37 \times 10^{-6}$,

Then for $t = 1.0 \times 10^{-6}$

$$\frac{E''}{E_a} = 0.081 \tag{28}$$

which is about half the value shown on curve 4 of the paper. If one substitutes $R = 0.0074$ for Z_1 and proceeds in a similar manner, the result is

$$\frac{E''}{E_a} = \frac{Z_2}{2Z_2 + R}\left[1 - \epsilon^{-\frac{(2Z_2 + R)}{RZ_2c}t}\right] \tag{29}$$

For the constants given, it is found that

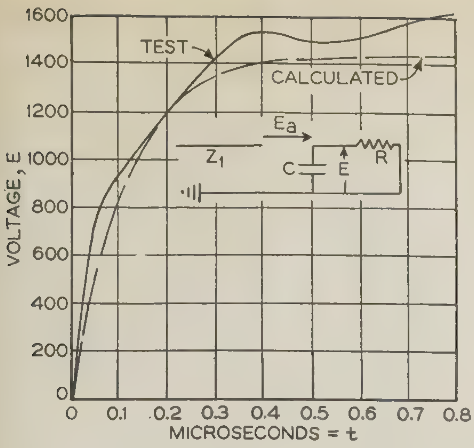
$$\frac{RZ_2C}{2Z_2 + R} = 0.00137 \times 10^{-6} \tag{30}$$

so that for all practical purposes

$$\frac{E''}{E_a} = \frac{Z_2}{2Z_2 + R} = 0.5 \tag{31}$$

for time from a very small fraction of a microsecond after the breaker is closed. This last result checks curve 5 of figure 7 of the paper.

Figure 6 of this discussion shows test data for a circuit which responds in exactly the manner expressed by equation 7 of this discussion. The noninductive resistance R can be substituted directly for the Z_2. This figure shows clearly that the difference between E_2 and E_a is correctly expressed by equation 7, and also that the rate of rise of voltage is even more closely calculated. In these tests the applied voltage E_a was that of the crest of the 60 cycle wave so that this ratio of E_2 to E_a could be experimentally determined. In Hunter's tests, the value of E_a was a matter of chance as no attempt was made to synchronize the breaker operation with the applied voltage. Further, no data are presented in the paper which show a rate of rise of voltage to crest of 1 to 3 microseconds. Such data are of most importance to the study of machine insulation during switching surges.



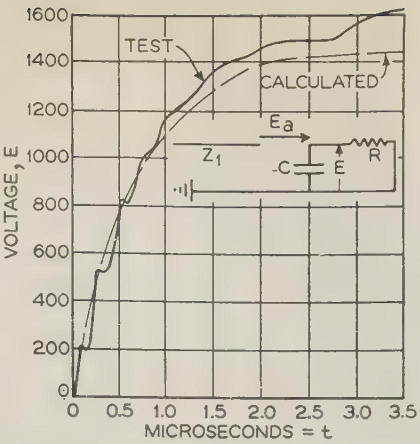


Fig. 6. Comparison of test and calculated data

E_a 3,110 volts
Z_1 600 ohms
R 516 ohms
C 0.0004 × 10^{-6} farads

E_a 3,110 volts
Z_1 600 ohms
R 516 ohms
C 0.0024 × 10^{-6} farads

$$E = E_a \frac{R}{Z_1 + R}\left[1 - \epsilon^{-\frac{(Z_1 + R)}{Z_1RC}t}\right]$$

$$E = 1440\,[1 - \epsilon^{-9t}]$$

$$E = 1440\,[1 - \epsilon^{-1.5t}]$$

E. M. Hunter: J. F. Calvert states that there is a fundamental difference between a switching transient and a lightning transient and to illustrate this difference gives equations to show the change in voltage which occurs when the 2 types of transients pass from a surge impedance Z_1 to a surge impedance Z_2. In the case of the lightning transient, if the junction between the 2 surge impedances were open, the open circuit voltage at the junction would be twice the incoming traveling wave voltage. An inspection of his equation 1 shows that it is this open circuit voltage $2E_1$ that is being reduced when the transient passes from Z_1 to Z_2. Likewise, an inspection of his equation 2 for the switching transient shows that it is the open circuit voltage E_1 that is being reduced. Since, in each case, it is the open circuit voltage that is being operated upon, mathematically at least, the phenomena is one and the same.

Calvert has pointed out that several factors were neglected in the method suggested in the paper for determining the transient turn voltages. This was done intentionally to simplify the solution. The approximations made can be justified since the results obtained are of sufficient accuracy for this type of calculation. With regard to the machine surge impedances given in reference 3 of the paper, the values given represented the best information available at the time that paper was presented. Additional information on surge impedance has been obtained since then.

With reference to figure 7 of the paper, curves labeled 1 and 3 should be labeled 3 and 1. Also, the magnitude of curve 4 should be reduced by half.

In connection with all of the discussion centering around the rate of rise of voltage at the machine terminals at the time the machine is energized, the importance lies not so much in the rates to be expected, but in the voltage stresses which occur in the machine winding. The field tests discussed in the paper show that there is an initial high concentration of voltage across the line terminal coils in the machine. The fact that these voltages were measured is sufficient evidence that the rate of rise of the voltage is very fast.

Insulation for High Voltage Alternators

Discussion and authors' closure of a paper by C. M. Laffoon and J. F. Calvert published in the June 1935 issue, pages 624–31, and presented for oral discussion at the electrical machinery session of the summer convention, Ithaca, N. Y., June 27, 1935.

J. C. Rah (Delta-Star Electric Co., Chicago, Ill.): This paper is very interesting not only from the standpoint of the approach to the design but from the viewpoint of the mica insulating tape used. Usually mica-bound tapes or tubes are a source of trouble to the designer, mostly because of the binding materials used to hold the split mica pieces together. Small air pockets in the tape are usually the most offending factor in those designs where the corona voltage is to be kept as high as possible. This is particularly important where the conductors are closely spaced and their insulated ends must be protected from flashover.

Since the question of air pockets in the laminated or composite insulating materials is of great importance in the design of insulated conductors in metal clad switchgear and underground boxes, molded or molded-laminated materials are used. Molded materials adapt themselves to high tension design, producing a homogeneous insulating body. With molded insulation, however, corona formation should be kept to quite high potentials. It is interesting, therefore, to know that good mica tape free from air pockets is available. Designs similar to the one described in this paper have been used in connection with metal clad switchgear, underground boxes, and cable and devices where conducting and semiconducting materials were used with very good results.

The potential distribution idea has not been used by designers as extensively as this method deserves. This is probably due to the fact that it has not been encouraged. We may still find textbooks that minimize the importance of the potential distribution as a logical aid to reduce corona and increase flashover potentials. Many designers overlook the effect of corona and streamer formation as long as the audible stage is not reached. This is one reason why I consider this paper of value as it brings out the points of increasing of corona potentials and the effect upon increasing the safety factor of equipment. The authors of this paper have demonstrated the usefulness of resorting to potential distribution in design in a practical way. This is particularly interesting as potential distribution and dielectric constant are considered by some as more or less of a theoretical value, and the increase of corona potentials as stretching the point a little too far.

I have used the potential distribution idea with very good results where insulated conductors were spaced closely. In metal clad switchgear and similar equipment, corona and its effects upon insulating materials, and metals as well, is of importance. The psychological effect is also great since it gives a feeling of unsafe equipment when one sees the inside of it illuminated by corona or streamers.

There is a point that the authors do not stress sufficiently and that is the experimental corroboration of the calculated values of the potential distribution with varying conditions of design. It is true that it has been my experience that the experimental results have usually been more favorable than the calculated values. If the authors had found an agreement between calculated and experimental values, it would be more convincing than the general results attained and described in this paper in eliminating corona at higher potentials.

The graded insulation idea has also been used successfully in equipment with close conductor spacing. Unfortunately, however, it has not found broader application to structure similar to that shown in figure 7 of the paper. In this type of support the important problem usually is the air space A. Filling this air space with materials having higher dielectric constants is not always successful unless the graded insulation principle is applied. Whenever possible it is more convenient to control corona by air distance A, and this distance depends upon the insulation of the conductors and is independent of the type of insulating material of the support. The results given in the curves of this figure fit very well with the results of my experiments with the exception that the rods in my design were not insulated. The effect upon the corona voltage in this type of structure is nearly the same whether insulated or bare rods are used. Figure 11 of the paper shows a 2-dimensional flux map. Such a map is of value to the designer only if the insulating materials have varied dielectric constants such as used with graded insulation principle or as an additional check on the de-

sign in general. Under "Design of End Windings," mention is made of "data obtained by visual observation in a specially made dark room." It is required usually to stay in the dark room 10 or 15 minutes before one can actually observe corona at such low voltages as treated in this paper. I have found that such observations can not always be reliable, as to depend on the eyes does not contribute to agreement on the observations. A much better method is to use a camera and a fixed exposure time. This means uniform results which can be compared and good records for future use.

H. H. Race (General Electric Co., Schenectady, N. Y.): The life of insulating materials in general depends upon their physical and chemical stability, i. e., changes in electrical quality, generally called aging, occur only as a result of physical or chemical changes. For machines which are to be in service for decades this question of stability is very important and I should like to suggest that for materials that are to be used either within or on the surface of armature insulation for purposes of grading electrical stresses, one important criterion is that they must not materially change their resistivity by vaporizing or drying up during years of service. Otherwise the protection afforded when the machine is new is lost as it grows older.

R. W. Wieseman (General Electric Co., Schenectady, N. Y.): This paper emphasizes the part played by recent developments of improved insulating materials and new methods of stator winding construction in opening the path for higher voltage machines. As a matter of fact, many of these features are not really new because they have been described in the technical press and used both here and abroad. For example, mica tape which is bonded with a low-loss bitumen varnish and continuously applied around the entire periphery of a coil, then bonded and filled, not with shellac, but with an improved bitumen compound, and finally treated and compressed in a vacuum-pressure tank has been used extensively by one manufacturer for many years. This method of insulating an armature coil with mica tape is now apparently superseding older methods of ironing mica sheet to a coil on the slot portion and then clamping it in a cold mould. The advantages of mica tape insulation applied as just outlined are briefly:

1. No joints occur at each of the corners of the coil.

2. The insulation on the ends of the coil is just as good as the insulation on the slot portion.

3. With low-loss bonding materials and a vacuum-pressure treatment, the insulation has a lower power factor, a lower dielectric loss, and a higher dielectric strength; in other words, a greater electrical endurance.

It may be of interest to review the status of 22,000 volt machines built in this country. Up to the present time 11 22,000 volt machines and 1 24,000 volt machine representing nearly 1,000,000 kva have been built. Incidentally, 92 per cent of these machines or 93 per cent of the kilovoltampere capacity were built by one manufacturer with improved mica tape insulation as described above. These machines have given reliable service and the same type of insulation would be used on 33,000 volt machines if they are required.

Gradient sheaths on the coil ends where the coil leaves the slot have been available for at least 10 years. A 36,000 volt machine operating in Belgium has this feature. Metallic ground sheaths of various types to reduce corona in the slots were used over 30 years ago. These ground sheaths have been superseded by improved higher resistance sheaths in the form of metallic paints, and ferrous asbestos armor tapes.

Internal sheaths which are described at length in the paper have also been used in this country and abroad. In fact, the highest voltage machine in this country, a 24,000 volt machine built in 1929, is equipped with internal sheaths. When 55,000 volts were applied to this machine between one phase and ground with the other 2 phases grounded, no discharge or corona occurred at the coils where they leave the slots. The only place where corona occurred was between coil sides where the phase belts terminated.

Grading high voltage armature insulation has enjoyed considerable popularity in recent years and 33,000 volt machines built in England in 1928 and in 1933 are examples of 2 different types of graded insulation. From a theoretical standpoint graded insulation should be beneficial when consideration is given only to machine voltages. Surge voltages, however, are known to travel through $^3/_4$ of a grounded neutral winding at practically full magnitude and if the neutral is not grounded, the neutral coils may be subjected to nearly double the voltage of the entering wave. Protective devices which reduce these surge voltages can be connected to the winding at the termination of each grade of insulation. This requires that extra taps be brought out from the winding and this may not be practical on a high speed machine where the space available around the end winding is limited.

In 1905 6 30,000 volt generators were operating in Italy and, as far as we know, these machines are in service today. In 1928 a 33,000 volt machine was installed in England and in 1931 a 36,000 volt machine was installed in Belgium. During this period generator capacities increased more than 10 times whereas generator voltages increased only 20 per cent. It is of interest to note that these high voltage generators (none of which exceed 35,000 kva) were pioneered in Europe where relatively large blocks of power are not distributed over long transmission lines.

In this country, except in metropolitan districts, any generator voltage which is now practical, is entirely too low to transmit large blocks of power. With large generators, therefore, it is still necessary to use step-up transformers in distributing large amounts of power. The voltage of smaller machines which have a more limited area of distribution might be suited to economical transmission. In these cases, however, the generator is more difficult to build for a high voltage than a large machine. The inherent difficulty with the small high voltage machine is obtaining the necessary turns to generate the voltage and then finding sufficient space to insulate the winding properly.

A 200,000 kva high speed generator has an economical voltage as low as 14,000 volts and a low speed generator of this capacity could be wound for a fraction of this voltage. Thus, as far as the generator itself is concerned, high voltages are not essential. Switching and bus bar difficulties, however, have increased the voltages of large generators above their economic values to 22,000 volts. The multiple winding generator has retarded somewhat the trend of increasing generator voltages and on this basis generator voltages may not exceed 22,000 volts until the multiple winding no longer limits the current per conductor to an economic value. A high voltage machine with its lower efficiency and increased cost will have little economic justification unless the step-up transformers are eliminated. In fact, H. M. Cushing's paper, "Design and Operation of Huntley Station No. 2" (Electrical Engineering, v. 54, June 1935, p. 632–45) specifically states that a 12,000 volt generator with an autotransformer is preferable to a 22,000 generator. With the present day voltage limit of mica insulated armatures set at about 36,000 volts and the transmission of large blocks of power confined to 132 and 220 kv, it follows that rotating a-c machines above 22,000 volts will have a rather limited field of application.

L. E. Frost (Brooklyn Edison Co., Inc., Brooklyn, N. Y.): In the discussion of this paper, some doubt has been expressed as to whether there will be any market for high tension generators in the United States. It may, therefore, not be amiss to recall that a substantial field for possible application of high voltage generators has been wide open for many years and that much of the seeming lack of interest in this direction has been due primarily to various limitations in generator design.

An increasing number of large power systems have been using voltages of 22,000 to 33,000 for primary distribution or subtransmission in localities of heavy load and high density. Generating stations located in these areas have frequently employed the feeder voltages for bus and switching equipment. Such stations have been equipped with large generators, sometimes the largest obtainable. Developments of this type would be the perfect setting for high voltage generators; but it has been expedient, so far, to use machines of lower voltages with step-up transformers in the leads to the busses.

The difficulties of obtaining reliable insulation have not been the only barrier against the use of high voltage generators. Construction costs and operating losses seem to be inherently higher than for low-voltage machines with such insulating materials as are available at present. The avoidance of autotransformers, of course, leaves some margin for increase in both of these factors. Indeed, it may be acceptable to have a poorer operating efficiency in a high voltage generator than in a combination of low voltage generator and autotransformers, if this deficiency can be offset by an advantage in the first cost of complete installation, taking account of the autotransformers and their connections, foundations, housing (if any), and space requirements.

For very large generating units, the autotransformer presents an attractive feature

in the facility with which its output windings may be divided into 2 or more circuits with desirable characteristics as to reactance and capacity. The split winding avoids the necessity of using circuit breakers of extraordinary current carrying capacity, and effectively limits the possible short-circuit currents. The same purpose has been accomplished with a double-winding generator without autotransformers, but I suppose autotransformer design would be more adaptable than high voltage generator design when there are exacting requirements as to reactance between circuits or amount of unbalance in load to be accommodated, or when more than 2 or 3 circuits are desired. The autotransformer also affords an opportunity to add a low voltage tertiary winding as an economical source of auxiliary power supply.

The Brooklyn Edison Company's most recent experience in this matter was in the provision of 2 200,000 kva generators to complete the Hudson Avenue station, which has 27,600 volt busses. Before this purchase in 1930, the bidding manufacturers were invited to suggest the most favorable generator voltage, and were informed as to the basis of evaluating operating efficiency. No 27,600 volt machines were offered. The successful bidder recommended and furnished 16,500 volt generators and step-up autotransformers. This combination was said to result in both the lowest construction cost and the best operating efficiency, in comparison with other designs by the same manufacturer. In this case the autotransformers have divided windings for 2 27,600 volt circuits per bank, and tertiary windings for 2,300 volt auxiliary supply. Alternate bids were received for 13,800 volt generators with autotransformers, which was the voltage combination already in use throughout the older part of the station.

The Hudson Avenue station alone has a total main generator rating of 951,000 kva (770,000 kw), all built since 1922, and all of which might have been in 27,600 volt generators if these had been available, reliable, and economical. Bus voltages of 22,000 to 33,000 have been found advantageous in a sufficient number of metropolitan centers to indicate a potential market for high tension generators which is by no means negligible in scope.

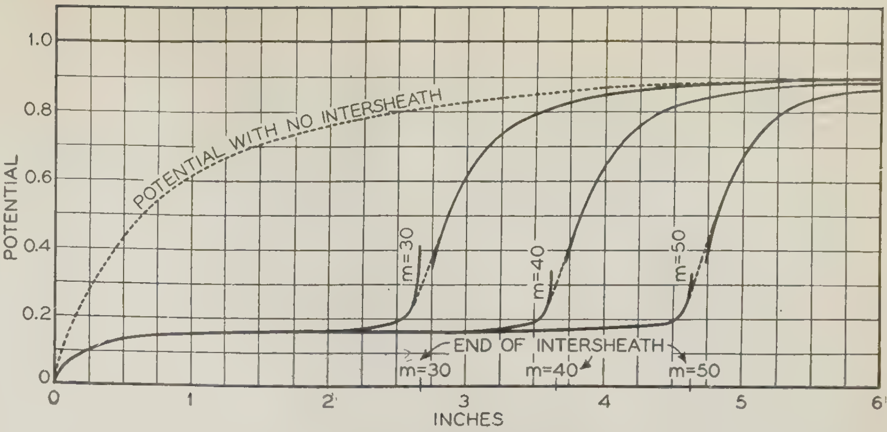


Fig. 1. Computed potentials on outer surface of insulation, showing effect of intersheath

Intersheath at $^1/_6$ depth; thickness of insulation 0.314 inch

P. L. Alger (General Electric Co., Schenectady, N. Y.): The authors have presented a very stimulating review of the various means that are available to designers for controlling voltage gradients and corona in high voltage generators. An especially interesting phase of the subject is the use of internal conducting sheaths embedded in the armature coil insulation in a similar manner to that frequently employed for high voltage bushings. As the authors point out, such internal sheaths, extending beyond the slot portion of the coil, serve to materially reduce and to taper off the surface voltage of the coil, and thus to minimize the corona discharges from the coil surface to the armature flanges and the adjacent coils.

Several years ago, Prof. A. A. Bennett made a theoretical investigation of this subject, to determine the optimum location of such intersheaths and the actual coil surface gradients they will produce. Figure 1 of this discussion gives a typical illustration of the results obtained. In the figure, the ordinates represent the potential from the surface of an armature coil to ground, expressed as a fraction of the potential of the conductor. The abscissa represents the distance along the surface of the coil end measured from the end of the slot. The dashed line shows the surface potential resulting when no intersheath and no surface conducting material are used. In this case, the potential rises to 60 per cent of the full value at a distance of only one inch from the end of the slot.

The 3 full lines show the surface gradient when the intersheath, embedded at $^1/_6$ the depth of the insulation, is extended for distances of 2.7, 3.7, and 4.7 inches, respectively, beyond the end of the slot, no surface conducting material being used in any case.

The interesting feature of these curves is the steepness with which the potential rises beyond the end of the intersheath, which indicates the correspondingly steep gradient existing in the body of the insulation at the end of the sheath.

The theory used in developing these curves involves some approximations, required because of the complexity of the problem, but the results obtained check reasonably well with test results. The short broken sections of the curves shown in the figure occur at the point where a change in the method of calculation is employed, because of the approximations involved becoming excessive.

Naturally, by judicious employment of semi-conducting paints or other materials, both on the surface and at the end of the intersheath, as mentioned by the authors, these high gradients can be controlled. At best, however, the design problem in securing desirably low voltage gradients throughout the coil end structure is one requiring much skill and attention to detail, so that considerable experience will probably be required before these methods are fully accepted in practice.

M. D. Ross (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is a very valuable contribution to the literature on high voltage electrical machinery outlining as it does an approach to the problem of designing machines for 33 kv or higher, adhering in most respects to accepted American practice. The authors have outlined a number of reasons why the work described in this paper was undertaken in spite of the present lack of demand in this country for machines above 24 kv. A further reason lies in the fact that American manufacturers are called upon to quote on such machines in competition with European designs, some of which have been in operation for some time and the construction of which differs radically from American practice. In order to be able to quote machines comparable in size and cost with European machines, it was necessary that this work be undertaken, developing the graded insulation design described in this paper. European purchasers are figuring on turbine generators as low as 12,500 kva rating at 33 kv. A machine of this size with uniform insulation on all coils would be much larger than one with graded insulation as the amount of slot space taken up by the insulation is a larger percentage of the total than in larger machines.

A factor influencing the use of 33 kv machines in this country is the tendency to distribute at a maximum of from 22 to 27 kv on closely knit systems and to go to 66 kv where the distribution is more widespread, leaving 33 kv in-between with relatively few applications. In Europe there are quite a number of systems distributing power at from 33 to 36 kv. Whether machines generating at 33 kv or higher and directly connected to the distribution system will be adopted in this country is a matter of economics. If such systems should prove to be more economical than the present methods of generation and distribution, they no doubt will be adopted in time.

F. W. Gay (Public Service Electric and Gas Co., Newark, N. J.): The authors state that generators wound for voltages appreciably higher than the present standards are larger, longer, and more costly than units wound for the most economical voltage. When a large station is designed to supply all or even a considerable part of its output to a high voltage network, it is becoming common practice to locate the step-up transformer bank adjacent to the generator and connect the generator windings to separately insulated transformer windings by relatively short leads. In all such cases the generator and its connected transformer

bank should be designed as a unit, and the generator may then be wound for the most economical voltage.

For instance, it is no longer necessary to connect a third of the coils under a pole in series in order to co-ordinate a plurality of coil voltages each having a separate phase angle into a geometric single-phase resultant. The coils may be series connected in groups of 2 or 3 and each of these groups may be star connected with 2 other similar groups to form a 3 phase circuit. It follows that 2, 3, or any convenient number of separately-insulated 3-phase circuits may be used and the transformer may be designed to co-ordinate these many circuits into a single 3 phase secondary circuit.

In an extreme case, 3 suitably chosen individual coils may be star connected to form a separately-insulated 3-phase circuit. The number of turns per coil in a generator so connected may be varied over wide limits and the coil voltage may obviously be made very high, end turn insulation being progressively increased. A generator so designed would have one-third as many separately-insulated 3-phase circuits as there were coils per pole.

While the manufacturers have done some investigation along these lines, I do not believe the possibilities have been adequately explored by operating men. The most economical and reliable combination will probably often be found in a generator of moderate voltage solidly connected to an adjacent transformer bank by relatively short leads.

J. S. Jamison (nonmember; Virginia Military Institute, Lexington): The authors have presented, among other things, an end shield which prevents high voltage gradients at the end of the grounding surface used on the straight part of the coil. In the appendix to their paper they have outlined a method of calculating the voltage distribution along this shield. Their method applies only to the case where the ratio of the resistance to the capacitance in each section of the shield is the same.

Another method of calculating this voltage distribution is to treat the shield as 3 interconnected transmission lines. Using the same assumptions as the authors, namely, negligible voltage drop along the inner sheaths, negligible inductance at normal frequency, and negligible leakage current through the insulation, the shield in figure 10 of the paper reduces to a transmission line in each of the 3 sections. An enlarged drawing of the shield is shown by figure 2 of this discussion for convenience in locating the lines.

In the inner section, the line consists of the sheath a and the external resistance R_1. The supply voltage in this line is a third of the applied voltage ($V/3$), the receiver voltage is $E/_{1a}$, and the load is the charging current I_1 of the 2 outer sections.

The line in the middle section consists of that part of sheath b in this section and the external resistance R_2. The supply voltage is the sum of a third of the applied voltage and the receiver voltage of the inner section (E_{1a}), the receiver voltage is E_{2b} and the load is the charging current I_2 of the outer section.

The outer line is made up of that part of the conductor in this section and the external

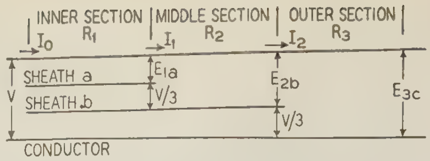


Fig. 2. Representation of intersheaths as interconnected transmission lines

resistance R_3. The supply voltage is the sum of a third the applied voltage and the receiver voltage of the middle section (E_{2b}), the receiver voltage is E_{3c}, and the line is open.

Well known equations for transmission lines can be applied to these 3 lines, giving the simultaneous equations:

$$V/3 = \mathrm{A}_1E_{1a} + B_1I_1$$
$$I_0 = A_1I_1 + C_1E_{1a}$$
$$V/3 + E_{1a} = A_2E_{2b} + B_2I_2$$
$$I_1 = A_2I_2 + C_2E_{2b}$$
$$V/3 + E_{2b} = A_3E_{3c} + 0$$
$$I_2 = 0 + C_3E_{3c}$$

in which A, B, and C are complex hyperbolic functions of the line constants for the different sections. A simultaneous solution of these equations will give the values of the voltages and currents at the extremities of each section of the shield.

With the supply voltage and current for each of the 3 lines known, the voltage between the external resistance and sheath or conductor can be found at any point along the shield by substitution in the equation.

$$E_x = E_s \cosh(u\,x) - I_s\sqrt{Z/Y}\,\sinh\,(ux)$$

in which E_x is the voltage at a distance x from the supply end of the line, E_s and I_s are the supply voltage and current, u is the complex line angle, and $\sqrt{Z/Y}$ is the surge impedance of the line. Using the same ratios of resistance to capacitance as used by the authors, the voltage distribution for their shield was calculated and the results obtained were substantially the same as theirs.

This method of calculating the voltage distribution has the advantage that it can be used for any ratio of resistance to capacitance in the different sections; however, it is limited to the case in which the resistance and capacitance per unit length remains constant in any one section.

C. M. Laffoon and J. F. Calvert: In reply to J. C. Rah's discussion, we feel that the dielectric loss factor of mica tape insulation will not be as low as that of molded materials. Furthermore, it must be kept in mind that where a low dielectric loss is required in mica tape, it must undergo a vacuum-gum impregnation process after being wound on the conductor in order (a) to get the solvents out and (b) to press the tape down by a sort of hydraulic pressing action.

We are in complete agreement with Rah concerning the importance of voltage gradients in rationally determining so-called "creepage distances" and "flashing distances" in design. We published in this paper the necessary data on the latter for rotating machine design. There are very few, if any, reliable data on the voltage gradient necessary for creepage over different types of insulating surfaces with different spacing of electrodes.

In designing the shield with only 4 external resistances (figure 8), we allowed a maximum voltage gradient of 20,000 volts (effective) per inch and a maximum I^2R loss of 1.0 watt per square inch with a test voltage on the insulation of 80 kv for one minute. Temperature was recognized as the limit in the design. No flashing occurred up to 100 kv, but above 80 kv excessive heating existed on a one minute test. The shield which carried up to 155 kv in air without corona was designed for from 150 to 180 kv. For the latter design, the surface heating on test was not calculated to be so great as in the former, and no heating trouble was experienced on test. It may be said, then, that these shields were rationally designed and test data substantiated the calculations quite satisfactorily.

We believe that sufficiently accurate data can be obtained by 2 dimensional field maps such as shown in figure 11 of the paper. Were it necessary to consider 3 dimensions and 2 dielectric constants to obtain sufficient accuracy, then modification of the methods presented by M. G. Leonard in the articles "Field Plotting in Non-Uniform Media" (*Elec. Jl.*, Dec. 1934, p. 471, and Jan. 1935, p. 31) will supply the data.

We recognize that it would have been more desirable to use photographic plates in securing the data on corona. Rah states that our data check closely with his. Since our data also were checked by a number of observers at the time they were taken, these facts furnish proof of fair reliability. It is sufficiently good to permit safe machine design, especially when one considers the vast amount of field experience available on machines up to 13.8 kv which can be used as a "bench mark."

H. H. Race's position concerning the stability of the semi-conducting compounds is very well taken. It might be desirable to say a few more words concerning such materials. They practically all are composed of either highly or partially conducting particles held together by insulating compounds. If highly conducting particles are used, the resistance is largely in the insulation between the particles. This is bad, because as the insulation dries out and possibly metallic oxides form, the resistivity per square inch of surface approaches 5,000 megohms or more. Aluminum paint is a fair example. Hence, somewhat jagged particles of inherently high resistivity held in intimate contact with each other by a varnish or shellac binder are the desirable arrangement. Such a semi-conducting paint may actually show a slight decrease in resistivity as the binder dries out and pulls the particles into more intimate contact with each other. These features were recognized by McCulloch, who produced these paints for us. On tests at from 100 to 125 degrees centigrade for 6 months no serious change in resistivity was noted. Also, no serious change was noted when other varnishes and insulating compounds were added after the semi-conducting coating had dried.

R. W. Wieseman describes the use of low loss bitumen base varnishes for mica tape as though all such fell in the same category. Actually there are myriads of ways of modifying this type of bonding material. For a number of years the company with which the writers are affiliated used a certain form of mica tape for quite a number of machines.

More recently development work was undertaken to obtain a still better mica tape insulation. One was obtained which has a lower dielectric loss and with which higher coil breakdowns are obtained than with any other mica tape which it was possible to buy from other suppliers. By comparison with the earlier mica tape which it superseded, the dielectric loss at elevated temperatures has been cut to half or less. The breakdown voltage has been increased 30 per cent. This, if not entirely new, is a distinct improvement.

However, there are applications where mica folium may be more desirable than mica tape. Mica folium when not mechanically damaged cannot be exceeded in dielectric breakdown by mica tape. We have had a rather wide experience with both mica tape and with mica folium, and we do not agree with Wieseman in his discussion of these 2 types of ground insulation. First, failures with mica folium do not occur more readily through the joint at the end of the folium than elsewhere. This may be attributed to the fact that the insulation wall is always heavier at this section, but experience bears out this point. An interesting feature regarding the type of breakdowns which occur in mica tape when tested to the point of failure has been brought out by our research associates. They have extracted the bond at the point of failure on a large number of samples. On these it was noted that the path of the puncture went either in a perpendicularly outward direction or axially between layers of insulation, never at much of an angle diagonally. Where the path of failure was perpendicular to the layers of insulation, it did not deviate $^1/_{16}$ inch to go around a flake of mica. The second point made by Wieseman regarding mica folium is correct, but in the end winding, about $^4/_5$ or more of the voltage is on the air between coils or between coils and ground, because of the large amount of air and the relative dielectric constants. This is true provided the spacing is sufficient to prevent corona, and is true at normal voltages for all well designed machines. Third, power factor and dielectric loss factor are almost the same thing. With proper bonding materials and pressing methods, the dielectric loss in folium is as low as it is in mica tape. Its long time or step-by-step breakdown is as good and its short time breakdown is as good or better than mica tape, because no joints perpendicular to the insulation occur as they do at the edges of the mica tape. The chief advantages of mica tape are that its use permits shorter coil extensions and greater flexibility on long coils.

A review of the paper and references will show reference to earlier forms of end shields. Almost any corona shield will prevent electrostatic discharge up to 50 kv in air. However, this paper describes other shield arrangements which were designed for from 150 to 180 kv and which on test prevented corona up to 155 kv in air. By raising this value 3 times and being able to predetermine the conditions, we believe a distinct advance was registered.

Graded insulation has very distinct advantages in reducing the cost and size of high voltage machines (22 to 36 kv). Wieseman has overlooked the fact that coils with concentric turns which were used in the Parsons Electric machines would so distribute the voltage as to prevent excessive voltages to ground, provided the neutral is grounded and the line voltage is limited. On machines with rectangular coils, even though the neutral is grounded, taps must be brought out at the junction between the high and low voltage windings for lightning arrester protection. (See reference 9 of the paper.) The leads to these taps do not carry more than 1 or 2 hundred amperes for perhaps 100 microseconds. Except for the lack of permanence of the insulation, ordinary lamp cord would be satisfactory. Obviously only small leads are needed here. However, it is not a serious matter to bring out 12 main leads on a machine and then to make all connections externally. It is not uncommon now to bring out 12 leads. For that matter there would be no great difficulty in bringing out 12 leads on each end of the frame by having 2 windings in the machine with the wiring around frame connections of one on the opposite end of the core from that of the other.

Many opinions have been expressed in this country and abroad concerning the merits of higher voltage machines as compared with those of the more usual voltage. It is our contention that only careful estimates on specific applications will yield reliable data and generator design for the higher voltage machines must be made with equal care for detail as has been done for the more usual voltage machines before such comparison will be of value. It has been our purpose to present methods of designing higher voltage machines which will be in accordance with the best American practices for machines of the more usual voltages and which can be used in making valid comparisons. We do not favor either the higher or the more usual voltage machine. We wish to be in a position to furnish data for valid comparisons, which we feel have not been possible before. It it proves that there are suitable applications in large metropolitan areas or in foreign markets, it is desirable to be in a favorable position to supply the need.

We were disappointed that this paper was not discussed by more representatives of operating companies. However, we do appreciate the discussion by L. E. Frost as representing the views of an operating engineer. We are in agreement with him that there is a potential market for generators of higher voltage in large metropolitan areas if they prove more economical when compared with lower voltage machines and autotransformers for the same specific applications. Such comparisons should be carefully made with due consideration being given to all factors entering into the over-all cost during the life of the machine.

In replying to P. L. Alger's discussion, we wish merely to refer to our replies to the discussions by Rah, Wieseman, and Race.

M. D. Ross points out more carefully than we have done some of the reasons for this study and some of the possible applications for such work. This is particularly helpful in view of some of the questions raised by other discussers.

J. S. Jamison has contributed a more complete solution for one of the end shield designs which we had calculated. We enjoyed co-operating in this work with him and were gratified to find that it furnished a satisfactory check on our early calculations.

An Advanced Course in Engineering

Discussion and authors' closure of a paper by A. R. Stevenson, Jr., and Alan Howard published in the March 1935 issue, pages 265–8, and presented for oral discussion at the education session of the summer convention, Ithaca, N. Y., June 26, 1935.

H. W. Bibber (The Ohio State University, Columbus): This paper will be of service not only as a means for acquainting all members of the Institute with the details of the advanced course, but also as a statement, made by representatives of a great industrial firm, to which students can be referred when, for example, they are dubious of the importance of the study of advanced mathematics as a preparation for creative work in electrical design. The published observations of such men may serve to support very effectively remarks made by a student's instructor.

The value of publishing in Electrical Engineering articles presenting the industry's points of view on engineering education is greater than that of putting these articles before the teachers of engineering, because of the fairly large number of student readers and the respect which is paid by students to Institute publications as reference matter.

This paper emphasizes the weight placed by industry upon training in the clear and concise presentation of investigations, a matter not always appreciated even by quite able students.

Another interesting feature of the paper is that it will show the value of an advanced study of fundamental principles of physics outside of electricity. The statement that the graduates of the 3 year course who go into electrical engineer ing departments have spent about $^2/_3$ of the time in the course studying mechanical engineering subjects should serve to indicate what is demanded for practical engineering to students who are impatient with the inclusion of these subjects in an electrical engineering curriculum.

The authors have noted that at the time the advanced course was instituted "the courses in many colleges had become too practical." Do the authors believe that in the years since the founding of the advanced course there has been a significant change in the preparation of the engineering college graduates hired by their company? Do they have evidence of graduates now having a greater knowledge of fundamental principles and ability to think in terms of them, as compared with 11 years ago?

While it is implied in some places, the paper does not contain expressly any philosophy on the value of combining considerable practice in engineering, approximately 36 hours per week, with 24 hours of outside problem work and class instruction. This would have some bearing on graduate work in electrical engineering in the colleges and universities, and I should like to ask how the authors would evaluate graduate instruction, which is given as well as is possible in academic surroundings and covers the same general field, as preparation for a future career in electrical or mechanical design.

A. R. Stevenson, Jr., and Alan Howard: Professor Bibber has asked 2 very pertinent questions. He inquires if we have noted evidence of a greater knowledge of fundamental principles on the part of graduates now as compared with 11 years ago. Such trends are, of course, quite hard to evaluate but it is our belief that there has been a change in this direction, although we cannot point to any definite statistics to corroborate this opinion. We are, of course, very glad to note that a number of the colleges and universities are reorganizing their courses so as to place greater emphasis on fundamentals and less on specialties.

Bibber also asks how we would evaluate graduate instruction similar to that given in the advanced course but conducted at a university. Referring to the classroom and home study activities, we can see no reason why these could not be conducted as satisfactorily at universities as we conduct them at Schenectady provided the same facilities and material are available. There are available at Schenectady a large number of practicing engineers who are experts in the various fields covered by the course work and give a large proportion of the lectures. Also, numerous sources provide actual engineering problems, many of which are assigned to the classes. We believe, therefore, that it would be very difficult for a university to maintain fully the viewpoint of the advanced course without the access to the speakers and problem material we are fortunate enough to have. Nevertheless, we feel very definitely that it is most valuable to the student when the fundamental point of view, which is the basis of the course, is emphasized in college work.

Two items not included in the original paper might be of interest here. The first is a list of the mathematical "tools" taken up in the first year of the course:

1. Ordinary differential equations
2. Partial differential equations
3. Fourier series
4. Dimensional analysis
5. Graeffe's method (root squaring)
6. Operational calculus
7. Numerical methods

We would like to emphasize that this mathematics is studied with the view that it is necessary for the solution of certain types of engineering problems and not because of direct interest in the mathematics as such.

The second item is the chart reproduced here, often used in the advanced course to illustrate the interrelation of the fundamental principles of the fields of mechanical, thermal, and electrical energy.

ADVANCED COURSE IN ENGINEERING—G. E. CO.

Engineering Fundamentals (Illustrative)

	MECHANICAL	THERMAL	ELECTRICAL
Basic Principles	Conservation of Energy Principle of Superposition Principle of Similitude Action Equals Reaction Virtual Displacement Conservation of "Momentum" Laws of Fields		
Special Laws	Newton's	Perfect Gas Heat Flow Carnot Cycle	Kirchhoff's Ohm's Ampere's
Definitions	Mass Force Velocity Strain Viscosity	Temperature Total Heat Specific Heat Latent Heat Entropy	Unit Pole Charge Potential Flux Resistance Inductance

Definitions of Power and Related Quantities

Discussion and authors' closure of a paper by H. L. Curtis and F. B. Silsbee published in the April 1935 issue, pages 394–404, and presented for oral discussion at the instruments and measurements session of the summer convention, Ithaca, N. Y., June 25, 1935. Other discussion of this paper was published in the October 1935 issue, pages 1120–1.

C. Budeanu (nonmember, Polytechnic School, Buchârest, Roumania): In the first place I am grateful to the authors for the attention they have given to the Roumanian works on this interesting chapter in electrotechnics. I affirm also with extreme satisfaction that all the fundamental ideas that I have had the occasion to suggest to them comprising these problems (see references at the end of this discussion) are in perfect agreement with the conclusions of the abovementioned report.

On the questions treated in this report, I wish to make the following reflections.

General Considerations

Properties of Conservation. These properties that arise from a fundamental physical situation give a different authority to notions of power.

Therefore I consider that the properties of conservation constitute the basic criterion for the definition of the notions, for the importance given to these notions as well as for the theoretical and practical methods in which we use them.

I remember that I have already shown that in a network without mobile contact, formed from J single-phase elements, the difference of potential and current of each element being noted with

$$\left.\begin{aligned} u &= \sqrt{2}\,\Sigma_1^n\, U_n \sin(n\omega t - \alpha_n) \\ i &= \sqrt{2}\,\Sigma_1^n\, I_n \sin(n\omega t - \beta_n) \\ \varphi_n &= \beta_n - \alpha_n \end{aligned}\right\} \quad (1)$$

the properties of conservation of the quantities of electricity (first law of Kirchhoff) and instantaneous power allow us to write the laws of general conservation of active powers, of reactive powers, and deforming powers for every harmonic and for every group of harmonics mn:

$$\Sigma_1^s P_n = \Sigma_1^s U_n I_n \cos(\varphi_n) = 0 \quad (2)$$

$$\Sigma_1^s Q_n = \Sigma_1^s U_n I_n \sin(\varphi_n) = 0 \quad (3)$$

$$\left.\begin{aligned} \Sigma_1^s D'_{nm} &= \Sigma_1^s [U_n I_m \cos(\alpha_n + \beta_m) - U_m I_n \cos(\alpha_m + \beta_n)] = 0 \\ \Sigma_1^s D''_{mn} &= \Sigma_1^s [U_n I_m \sin(\alpha_n + \beta_m) - U_m I_n \sin(\alpha_m + \beta_n)] = 0 \end{aligned}\right\} \quad (4)$$

From these relations results:

(*a*) The property of the algebraic conservation of total active powers:

$$P = \Sigma_1^n P_n = \Sigma_1^n U_n I_n \cos(\varphi_n)$$

(*b*) The property of the algebraic conservation of total reactive powers:

$$Q = \Sigma_1^n Q_n = \Sigma_1^n U_n I_n \sin(\varphi_n)$$

(*c*) The property of the vectorial conservation of deforming powers of the order mn:

$$D_{nm} = \sqrt{(D'_{nm})^2 + (D''_{nm})^2} = \sqrt{U_n^2 I_m^2 + U_m^2 I_n^2 - 2U_n U_m I_n I_m \cos(\varphi_n - \varphi_m)}$$

(*d*) The property of the vectorial conservation of total deforming powers:

$$D = \sqrt{\Sigma(D_{nm})^2} = \sqrt{\Sigma[U_n^2 I_m^2 + U_m^2 I_n^2 - 2U_m U_n I_m I_n \cos(\varphi_n - \varphi_m)]}$$

(*e*) The property of the vectorial conservation of apparent powers:

$$P_{ap} = \sqrt{P^2 + Q^2 + D^2} = UI$$

All these notions have therefore a physical character; they are not merely some arbitrary magnitudes. In the studies mentioned in the references at the end of the present discussion the application of these properties is given.

On the other hand, the properties of conservation are the principal criterion which enables us to distinguish the magnitudes having a physical character from those of a purely conventional nature.

The Normal Order of Definitions. The above properties of conservation give a different authority to the notions of active power, reactive power, and deforming power, as a consequence of the properties of conservation of instantaneous powers and quantities of electricity which constitute the true physical reality in all these phenomena.

In consequence, there should be no possibility left of interpreting the deforming power as a definite conventional magnitude only, by way of:

$$D = \sqrt{P_{ap}^2 - P^2 - Q^2}$$

The properties of these notions should result independently of the apparent powers P_{ap}.

The Nomenclature of Magnitudes. As is shown in the report under discussion, the question of the nomenclature on magnitudes still constitutes an important subject for discussion.

I entirely agree with the conclusions of the report on the fact that it is not desirable to term the magnitudes by the units that measure them.

Concerning the terminology of "distortion power," I bring up the reference to the notion in which I introduced it under the term of "deforming power." I have no objection whatsoever to the rightly called term which is adequate for the official organizations and especially to the International Electrical Commission. The notion, which is interesting in itself, must be upheld.

On the terminology of magnitudes I beg to draw attention to a very judicious point of view expressed by M. Blondel.

He, to avoid any kind of confusion whatsoever, wishes to keep the expression "power" only for active power, but for the other notions of the group of dimensions of power, he proposes a new terminology.

Thus M. Blondel utilizes the term "hormanance" for "reactive power" and "mutual hormanance" for the notion which I have termed provisionally "deforming power" (distortion power).

The expression "apparent power" is retained; this being able to contain elements of active power as well.

Nomenclature for Unities. In practice, a great necessity has been felt for a terminology for the unit of reactive power. Based upon the proposal of the Roumanian Electro-technical Committee, the Interna-

tional Electrotechnical Commission admitted the term "var," formed from the initials of volt, ampere, and reactive volt-amperes.

The term "var" is easily adapted for all usual prefixes and suffixes: *e. g.*, "kilovar," "varhour," "kilovarhour," etc.

This practical term is today almost entirely adopted by the world of technics.

Insufficient Definitions of $\sqrt{P_{ap}^2 - P^2}$. This definition has for a long time been favored to characterize reactive phenomena, in a nonsinusoidal system. On the other hand, this notion has been very much criticized. As I have pointed out on different occasions, the definite notion of the above formula gives nothing precise and can be interpreted as an arbitrary definition (see page 34 of reference 2).

However, in reality, taking into account these expressions as stated under "Properties of Conservation," we have:

$$\sqrt{P_{ap}^2 - P^2} = \sqrt{Q^2 + D^2}$$

It results therefore that the notation $\sqrt{P_{ap}^2 - P^2}$ can be regarded as the vectorial sum of reactive power Q and of "distortion power" D. Therefore, we have brought into evidence, these 2 distinct categories of phenomena, of a reactive and deforming nature that remain the basis of the magnitude $\sqrt{P_{ap}^2 - P^2}$. On the other hand, the same analysis shows us that the magnitude $\sqrt{P_{ap}^2 - P^2}$, if it has not the property of an algebraic conservation, is, however, possessed of the property of vectorial conservation.

On the Separating of a Nonsinusoidal Circuit into Several Sinusoidal Circuits. It is evident that the method of Fourier gives us the possibility of a like decomposition when it is a question of nonsinusoidal function. Still, I do not believe that when it is a question of *magnitude of powers* we can be satisfied to break down our network into several identical classes, under, however, the sinusoidal currents and voltages corresponding to the different harmonics.

Proceeding thus, we are not able to put forth the real value of instantaneous powers; in consequence, the notion of deforming power (distortion power) would disappear and thus we could not arrive at the real value of apparent powers.

Detailed Considerations

I propose to bring forward the following considerations of detail:

(*a*) It is true that it is preferable to have all definitions as complete as possible, but it is not less true that we must distinguish the magnitudes that have a physical significance from those that have a purely conventional character or the rôle of a magnitude of calculation.

(*b*) Generally, the properties of conservation allow us to establish in every case that the total power which enters a portion of the network is equal to the sum of the powers developed in whole of the elements of those portions of the network.

This property is applied under an algebraic form for instantaneous powers, active and reactive powers and under a vectorial form for deforming powers (distortion powers) and apparent powers.

These properties of conservation must be inscribed among the fundamental properties of all these notions.

(*c*) A distinction must be made in the active power, as well as in the reactive power and in general in the instantaneous powers and even in the deforming powers between "produced powers" and "received powers."

Thus, for instance, the expression "inductive reactive power," is not sufficient to characterize the sign and sense of these reactive powers.

The inductive-reactive power *produced* by a generator is of a sense opposed to the inductive-reactive power *received* by an induction coil.

(*d*) I consider it preferable, on the consideration of physical properties, to adopt the following order of definitions: real power, reactive power, deforming or distortion power, and after, apparent power.

(*e*) If we give for apparent power as a property, that through its multiplication with cos φ, under sinusoidal conditions, it obtains real power, we must *at once pronounce also* the property that through multiplication with sin φ reactive power is obtained.

(*f*) I quite agree with the definition adopted for the reactive power in circuit with nonsinusoidal currents and potential differences, because of the considerations I have developed in various studies and reports.

(*g*) The reactive power, as applied to circuits in which the currents and potential differences are sinusoidal, has the property of being able to be written under the formula

$$Q = 2\omega\,(W_m - W_e) = 4\pi f\,(W_m - W_e)$$

where W_m is the stored electromagnetic energy and W_e the stored electrostatic energy.

Now, I have shown that even when the currents and potential differences are nonsinusoidal we can have an analogous expression (see reference 11) in which ω has a well-defined average value between the fundamental wave and different harmonics.

(*h*) I consider it preferable that the distortion power should be defined by its properties that are deduced from the principle of conservation.

About the terming of these notions, as I have pointed out, I have no objections whatever. I consider it very interesting that the notion itself has been retained.

(*i*) About the terms for fictitious power, I should like to draw attention to the fact that the committee for reactive power was of opinion to term it "complementary power."

(*j*) In balanced polyphase circuits, the principle of conservation easily brings into evidence the total value of real power, reactive power, and deforming power. I have examined several special cases that have led to interesting results (see page 295 of reference 1). Thus, I have shown, for instance, that in a 3-phase balanced system with different sinusoidal potentials and nonsinusoidal currents, the total apparent power is smaller than 3 times the apparent power in each phase.

(*k*) In an unbalanced polyphase circuit the notions that are of direct interest are the active, reactive, deforming, and apparent powers in *every phase* and after that, the total active power which can easily be defined, and in some measure the total reactive and deforming powers.

Among the notions of apparent power, the only one which appears in connection with the properties of conservation is the vector power.

All the other definitions such as *arithmetic* apparent power, algebraic apparent power, mesh power, etc., have no physical character issuing from the properties of conservation.

(*l*) By the same considerations in the case of *unbalanced polyphase circuit under nonsinusoidal conditions*, the total deforming power (distortion power) is the vectorial sum, but not the algebraic sum of the elementary deforming powers.

This vectorial sum must be taken in a space with several dimensions as results from its properties of conservation.

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A. E. Kennelly (Harvard Univ., Cambridge, Mass.): The paper is a valuable and timely contribution to the important but vexed subject of a-c power nomenclature. The following remarks are offered from the standpoint of international proposals of the I.E.C.

Right-Angle Triangle Power Diagrams. Figure 1 of the paper, on page 397, shows the conventional power diagram for a single-phase condensively reactive load of resistance and capacitance, according to the I.E.C. rule for interpreting unspecified power triangles. It is admitted that this same diagram may correctly be taken to represent either condensively reactive or inductively reactive load, according as the impressed electromotive force vector E or the impressed current vector I is made the standard of reference. (See "Vector Power in Alternating-Current Circuits," A. E. Kennelly. A.I.E.E. Trans., v. 29, pt. 2, 1910, p. 1233–67.) When there is no indication accompanying the diagram to fix its basis, the I.E.C. convention of $P - jQ$, at Paris, in 1933, for inductively reactive load, has to be invoked.

If, however, the rule should be interpreted to mean that inductively reactive load can only be presented in a diagram under the form $P - jQ$, then it might be inferred that the impedance of a coil must be $R - jX$ ohms; whereas the I.E.C. resolu-

tion at Turin, in 1911, has universally been adopted that a coil's impedance is essentially $R + jX$.

Vector and Apparent Power Factors. The paper shows that a steady unbalanced 3-phase system when operated by a sinusoidal or simple harmonic 3-phase generator, has a vector power factor $P/\sqrt{P^2 + Q^2}$, which is identical with the apparent power factor $\Sigma P/\Sigma(EI)$. If, however, the generator impresses complex harmonic electromotive forces, the apparent power factor will differ from the vector power factor, and will also be ambiguous; i. e., the apparent power factor will vary according to the selection of the terminals for measurement. It seems, therefore, desirable for the present, to emphasize the importance of the *vector power factor* of a polyphase system as a fundamental property of the system, and to make the measurement with generators having relatively small departures from sinusoidal electromotive forces. The I.E.C. recommendation of Stockholm, in 1930, for a sinusoidally measured polyphase power factor was $P/\sqrt{P^2 + Q^2}$, which is identical with the vector power factor defined in the paper here under discussion.

Construction of Plane Vector Diagrams. Since 1893, electrical engineering has extensively employed the j operator (or $\sqrt{-1}$ operator) for extending a plane vector by the addition of an element perpendicular to a fixed direction of reference (see "Impedance," A.I.E.E. TRANS., v. 10, Apr. 1893, p. 186). Thus, in figure 1 of the paper under discussion, we all recognize that the vector power U is $P + jQ$, where P has the fixed direction of reference.

Similarly, in figure 3, the vector power V is $\Sigma P + \Sigma jQ$, where the P elements all have the fixed direction of reference.

In the construction of plane vector diagrams, however, there is often an advantage in changing the direction of reference as the construction develops, and in applying the j operator to the *latest* vector in the process. Thus, if we use the symbol j' to call for the addition of a vector element perpendicular to the instantaneous stage of construction, we have, in figure 3, apparent power $U = V + j'M$, where the mesh power M is drawn perpendicular to V, and not to P. Hence, $U = \Sigma P + \Sigma jQ + j'M$.

It is well known that the total effective value of a periodic or nonsinusoidal electromotive force $E = E_1 + E_3 + E_5 + \ldots E_n$, is $E = \sqrt{E_1^2 + E_3^2 + E_5^2 + \ldots E_n^2}$ where E_1 is the fundamental component, and E_3, E_5, etc., are the harmonic components. This may be written with the use of the j' operator, $E = E_1 + \Sigma\, j'E_n$. This j' process is sometimes colloquially described as "crab addition."

E. Brylinski (nonmember, Paris, France): I offer my congratulations that this work has been done and with so much care. The paper is perfectly clear.

However, if one attempts to develop any matter in so complete a manner, great complications must necessarily arise and I am not yet entirely certain that it is ever worth while to go into such detail as here indicated.

The one point in this paper which clashes with my habits of thought in these matters is the proposal to adopt as units, "vectorial" volt-amperes, "distorted" volt-amperes, "fictitious" volt-amperes. For me the volt is a definite unit which does not accommodate itself to any qualifying adjective. The same applies to the ampere and also to the volt-ampere. Every time I see such an expression as "vectorial" volt-ampere, or "fictitious" volt-ampere, or "reactive" volt-ampere, it gives me something of a shock. I think I would have great difficulty in accommodating myself sufficiently to any of these expressions to accept them as standards, for the same reasons that I have always refused to accept the expression "reactive" volt-amperes or "reactive" watts, which is worse. It is for these reasons that I have been one of the principal advocates of the movement which has resulted in the designation of the unit of reactive power by the word "var."

H. B. Smith (Buffalo, Niagara and Eastern Pwr. Corp., Buffalo, N. Y.): The authors of this paper are certainly working for a good cause, and have done a good job of presenting the matter involved to the engineering public. A standard system of names for power quantities should be appreciated by all of us. However, in drawing up such a system we should not be satisfied with just a name. In choosing these names, we should be guided by the specification that they appear logical and be easy to remember. Anything which tends to make the system of names easy to remember should be worth consideration. If we adopt a system which is hard to remember, the result may be that many will not try to use it—the system will be adopted in theory but not in practice. Therefore, we should even be willing to put up with some disadvantages in a system of names, if it has the advantage of being easy to remember and, hence, likely actually to be used after adoption. A general rule for drawing up a system that can be easily remembered might be: reduce the number of different words to a minimum where possible, choose words that are suggestive, and make related quantities appear as such through their names. If necessary, the logic in naming a quantity need not be along the same lines as the mathematical process in determining the value of that quantity.

(*a*) Assuming that this general rule for drawing up a system of names is reasonable, I find that the system presented by the authors does not satisfy. Refer to the authors' figure 2, page 398. The line F is called "fictitious power" but actually the quantity represented is no more "fictitious" than several of the other quantities represented in the diagram. The line N is called "nonreactive power" but the quantities represented by lines P and D are also "nonreactive" power quantities.

(*b*) The authors present 3 varieties of "apparent power" for unbalanced polyphase circuits with nonsinusoidal voltage or current:

Arithmetic Apparent Power. It is admitted that the quantity represented by this term "has none of the properties of apparent power in either of the simpler types of circuits." The A.I.E.E. in 1920 omitted it in their standards. According to the authors "a number of engineers have urged its inclusion, possibly because it can be readily obtained from measurements with ammeters and voltmeters." It cannot always be used in determining load limit of polyphase apparatus. In view of the above, I would omit it in a standard system of power terms.

Algebraic Apparent Power. This quantity has the point in its favor that it possesses property (*d*)—see the authors' article, page 396. It appears to be a quantity which can be calculated, but which can be measured only with more or less difficulty. Hence, for general use, its value seems questionable.

Limiting Apparent Power. This quantity is easy to measure. It has value in being a very safe (pessimistic) quantity to use in determining load limits of polyphase apparatus. For example, in the case of a 3-phase unbalanced load made up of 3 unequal single-phase loads, if the "limiting apparent power" is measured and used to fix the size of 3 single-phase transformers supplying the load, it would be impossible to overload any of the transformers, regardless of how the different phases of the load were connected to the transformers.

Based upon the foregoing, it seems to me that the best "brand" of apparent power to use is the "limiting apparent power." It has both the virtues possessed by the other 2 "brands," and has an additional virtue in that it would always be a foolproof means of determining required apparatus capacity for an unbalanced polyphase load.

(*c*) One thing that is true of all 3 of the above mentioned kinds of "apparent power" is that none of them is a vector (even in the sense that the other quantities in figure 4 are vectors). Similarly "mesh power," which is defined in terms of one of the 3 above quantities and "vector power," is not a vector quantity. Hence, to be correct, we should not show any of these quantities in a power vector diagram such as figure 3 or figure 4. At any rate, if we do tolerate their presence there, we certainly should not allow them to have any effect on our logic or judgment in naming and representing the other quantities which bear vectorial relations between each other. Furthermore,

Table I—Proposed System of Power Terms

Line in Power Diagram (See Figure 1)		Proposed System		Curtis and Silsbee System	
1-phase load	Unbalanced 3-phase load	Name of Quantity	Symbol	Name of Quantity	Symbol
o-a	*o-a'*	active power	P	active power	P
o-b	*o-b'*	reactive power	Q	reactive power	Q
o-d	*o-d'*	vector power	V	vector power	V
o-c	*o-c'*	distorting power	D	distortion power	D
o-e	*o-e'*	distorted active power	P_d	non-reactive power	N_i
o-f	*o-f'*	distorted reactive power	Q_d	fictitious power	F_i
o-g	*o-g'*	distorted vector power	V_d	apparent power (single phase only)	U
	o-k	limiting apparent power	U	arithmetic / algebraic / limiting } apparent power	U
	g'-k	mesh power	M	mesh power	M

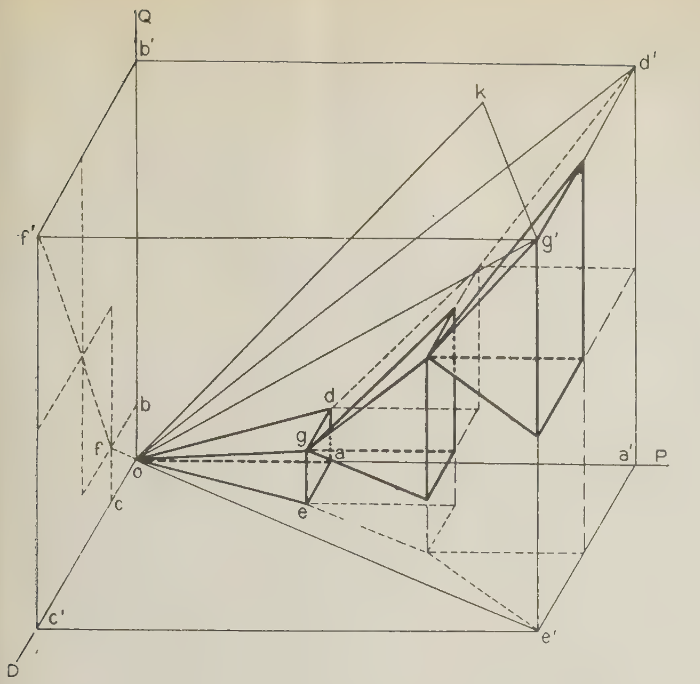


Fig. 1 Power diagram for unbalanced 3-wire polyphase circuits with nonsinusoidal current or voltage waves

since, in figure 4, U and M are present only through courtesy, we should give line a-d (a vector) a name so as to make this 3-dimensional power vector diagram complete, just as was done in figure 3. A name for a-d, in accord with the system of names presented by the authors would be "vector apparent power," as contrasted with "arithmetic" and "algebraic" apparent power.

Proposed System of Power Terms

In conclusion, I should like to offer a different system of names. Perhaps this can best be done by means of table I and figure 1. Figure 1 is a copy of Curtis and Silsbee's figure 4, except for the lettering.

Using the symbols in the proposed system of table I, and referring to figure 1, we have:

$$V^2 = P^2 + Q^2$$
$$P_d^2 = P^2 + D^2$$
$$Q_d^2 = Q^2 + D^2$$
$$V_d^2 = V^2 + D^2 \text{ or } V_d^2 = P^2 + Q^2 + D^2$$

To the writer, it seems that this system satisfies fairly well the so-called general rule previously mentioned. Corresponding with the 3 axes in the diagram, we have "active power," "reactive power" and "distorting power." Should we know these 3 basic power quantities for a particular circuit, all other power quantities could be derived. Hence, it would seem reasonable to choose names for these other quantities which will give some clue as to relationship. Furthermore, it seems reasonable to expect that such a system of names will be easier to remember and use than a system made up, in part, of nonrelated names.

By way of justifying the system proposed by the writer, the following is pointed out (refer to accompanying figure 1):

Consider only one phase of the unbalanced 3-phase load represented.

1. If the load were pure resistance, and if current and voltage waves were sinusoidal, the total volt-amperes present would be represented by the line o-a—"active power" (P).
Now, if there are harmonics present in the voltage or current wave, the line representing total volt-ampere changes from o-a to o-e—"distorted active power" (P_d).

2. If the load were pure reactance, and if current and voltage waves were sinusoidal, the total volt-amperes would be represented by line o-b—"reactive power" (Q).
But if the current or voltage waves have harmonics, the line representing total volt-amperes is changed from o-b to o-f—"distorted reactive power" (Q_d).

3. If the load contained both resistance and reactance, and if current and voltage waves were sinusoidal, total volt-amperes would be represented by line o-d—"vector power" (V).
Again, if the current or voltage waves contain harmonics, the line representing total volt-amperes is changed from o-d to o-g—"distorted vector power" (V_d).
In each of the 3 cases assumed above, it is noted that the quantity which is responsible for changing "active power" to "distorted active power," "reactive power" to "distorted reactive power," and "vector power" to "distorted vector power" is the power quantity represented by the line o-c, Hence, it seems logical that this quantity be named "distort*ing* power" (D) since, when present, it distorts any of the other power quantities.

J. J. Smith (General Elec. Co., Schenectady, N. Y.): In 1928 the A.I.E.E. translated and printed the Rumanian questionnaire on the subject of reactive power. The replies to this questionnaire and the discussions have been printed by the committee on the subject in Europe and embrace 16 volumes and several hundred pages. The committee did not arrive at definite recommendations.

This paper gives concrete proposals for the various terms. For single-phase circuits and balanced polyphase circuits under both sinusoidal and nonsinusoidal conditions a single set of definitions is given which seems to meet any reasonable requirements. For the unbalanced multiphase circuit there is still work to be done. It will be noted that there are 3 different definitions for apparent power, namely, arithmetic apparent power, limiting apparent power and algebraic apparent power. I assume that conflicting opinions on this subject made it desirable to include the alternative proposals. It would have been helpful if the authors had seen their way to definitely recommend only one definition for apparent power.

To arrive at one definition it will be necessary to make a decision on how far we shall go in attempting to apply the concept o power factor to the different effects which occur in power circuits. These effects may be listed in the order we meet them in considering such circuits.

a. Displacement of voltage and current waves
b. Presence of harmonics
c. Presence of unbalances
d. Pulsations (steady)
e. Load factor (demand)

It seems pretty generally agreed that the displacement of current and voltage waves and presence of harmonics should be handled under the apparent power concept and that the load factor should not. Unbalances and pulsations are not definitely covered at present and a decision should be reached that they will or will not be handled by attempting to incorporate them in apparent power. Some disposition will have to be made of them before the quantities relating to power, power factor, etc., are definitely settled. If no other way of arriving at a decision can be found, possibly a letter ballot similar to those previously used by the authors would give an answer.

In arriving at such a decision it will, of course, be advantageous to have a clear statement of what the problem of reactive power is. I would submit the following which is along the lines already given by Prof. C. E. Budeanu in "Puissances Réactives et Fictives," published in 1927. In this summary the term "reactive power" is used to denote all components of the apparent power which are not active power.

The object of the study of "reactive power" may be seen from an examination of the effects produced on a power network, which are:

1. The "reactive power" required by a user must be produced somewhere in the power system.
2. The "reactive power" must be transmitted from the point of generation to the user. This transmission produces effects similar to the transmission of real power such as a loss of power in the transmitting network and a lowering or change in voltage.
3. The transmission of "reactive power" through a distribution network ties up a part of the capacity of the network for this reactive power and as a consequence diminishes its capacity for the transmission of real power.

It is evident that items a and b, the displacement of voltage and current waves and the presence of harmonics, contribute to effects outlined under items 1 to 3. Item (e), load factor, also contributes to these effects but it has already been found suitable to cover it by demand factor as pointed out by the authors in section 9.

Pulsations, item (d), arise from the electrical coupling of mechanical systems and introduce frequencies which are in no way related to the fundamental frequency or its harmonics. It would, therefore, seem advisable to handle these effects on a separate basis as has already been done in the case of load factor.

As regards item (c), if we consider the presence of unbalance on a power system as giving rise to effects on the power network which are equivalent to those produced by phase displacement and harmonics and if we desire to include all of these effects under the heading of power factor we are led to adopt the definition of limiting apparent power and discard those of arithmetic or algebraic apparent power. For instance, consider a 3-phase circuit with balanced voltages and a resistance load connected between 2 lines. The ratio of the active

power to the arithmetic or algebraic apparent power is unity. The ratio of active power to the limiting apparent power, considered as a single-phase load, is also unity. However, if we consider this unbalanced load as a 3-phase load the ratio of the active power to the limiting apparent power is 0.58, and thus we get a definite distinction between a balanced and an unbalanced type of load.

As an alternative, of course, we might endeavor to frame our definitions so as to include only active power, reactive power, and distortion power, keeping the unbalance power separate. In the latter case we might use the definitions given of arithmetic or algebraic power. If this is done, however, we are immediately faced with the problem of defining an additional factor for practical power systems which we may designate as unbalance power, and such a definition should be proposed for consideration.

I hope that the discussion which ensues as a result of this paper will eventuate in a decision on what quantities are to be included in the concept of apparent power. With this definitely settled the broad outlines of the definitions to be used would be fairly well established and it should not prove a very difficult matter then to agree upon the final details.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In this paper the authors have attempted to define the power relations of a nonsinusoidal single-phase system in the form of a geometric power diagram for periodic conditions. In deriving this concept they have defined new terms, such as, "distortion power," "fictitious power," and "nonreactive power." The authors have attempted to present a series of definitions which would cover all of the power quantities which are likely to be found useful and have attacked this problem in a fundamental way. Such a procedure seems very desirable as it avoids the necessity for radically revising the terminology for each minor advance in application of power quantities and related terms.

While the paper presents definitions of a fundamental nature it must, of course, be fully appreciated that many of the terms will not be found useful at this time and some perhaps may never be used by the operating or designing engineer.

The simplest type of single-phase circuit having *n* harmonic frequencies has *n* degrees of freedom, each harmonic acts as if the fundamental and the rest of the harmonics were nonexistent. Each harmonic has its own independent I^2R loss, its own power, reactive, and apparent power, quite independent of the coexistence of the other harmonic quantities. If we think in terms of the dynamical theory of currents, the generalized equations of motion for each of the components of harmonic current are derived separately from the Lagrangian energy function and are considered as independent entities. This is how the solutions are carried out in practical work. Generally in actual systems from the point of view of power and reactive power the higher harmonics are of little importance because when they are present in sufficiently large quantities as to be noticeable means such as harmonic filters must be employed to reduce them to tolerable values. After a specific problem has been solved in the manner indicated, it can be set up in the form of the diagram of figure 2 but that it will be helpful in visualizing the results of the solution appears to me to be extremely doubtful.

The above is concerned with the simplest type of nonsinusoidal single-phase system, but more complex systems exist in which the harmonics are functionally related to one another. In simple language, there is a frequency transformation in the system. The examples of such circuits are those containing iron which is subjected to saturation, and circuits in which there are arcs. It is difficult to visualize how the analysis of a system of such a character could be helped by the power diagrams or new definitions.

Where consideration is given to nonsinusoidal 3-phase systems, the complications are multiplied by 3 for the unsymmetrical case. This leads to extensions of terminology by the use of symmetrical components. Power and reactive power interchanges between phases add to the difficulty of the problem and of the terminology.

I believe that it will frequently be found convenient in dealing with a nonsinusoidal system to characterize it by defining each harmonic, its power and power reactor, and phase relation at some specified time to the fundamental frequency on some other suitable data. These are simple definitions and are well understood by most students.

K. Küpfmüller and **W. Quade** (nonmembers): (Abstract). In addition to the discussions published herein there were received 2 other foreign discussions from K. Küpfmüller of Danzig and W. Quade of Karlsruhe, Baden, Germany, respectively.

Küpfmüller pointed out the futility of introducing terms which have no practical significance or use at present.

Quade called attention to a totally different and alternative procedure by which it is possible to extend power concepts to nonsinusoidal cases and to polyphase circuits. This method is set forth in his articles in Archiv für Electrotechnik, volume 28, 1934, pages 130 and 798. By following this procedure he arrives at a quantity which for single phase circuits is the same as that which the present authors call fictitious power but which Quade calls "blindleistung," which is the usual word for reactive power. In the polyphase circuits there is no direct equality between the quantities arrived at by the 2 methods.

H. L. Curtis and **F. B. Silsbee:** We would like to express our appreciation of the careful consideration which the critics have given to our paper. We realize that the subject matter is, at present, controversial. One of the principal purposes of the paper was clarification of ideas by stimulating discussion. We feel that something has been accomplished in this direction since the critics agree on a number of points, although they disagree on others.

The criticism has been made by Lyon, Pratt, J. J. Smith, and Küpfmüller, that we have defined too many quantities, some of which are of no practical use and which will not be used in the future. We have, with one exception, defined only those quantities which are already in use, but many of which have not had names that uniquely identified them. We began the consideration of this subject at the request of the American Standards Association committee on definitions who wished to clarify the situation for the benefit of the readers of the future. If useless terms have been defined, there is no compulsion on anyone to use them, and they will soon disappear from the literature.

Budeanu and Lyon both object to our treatment of "distortion power." The former objects because we do not assign to it a physical reality, and points out that it is vectorially conserved if its components are properly combined (which can only be visualized by conceiving space of many dimensions). The latter, on the contrary, objects to defining it at all on the ground that it is not a useful concept and gives an example to show that distortion power is not algebraically additive even in the simplest circuits. The authors realize the limitations pointed out by Lyon and admit the possibility of a detailed treatment such as desired by Budeanu. However, our purpose was merely to provide a suitable nomenclature for concepts which some authors are now using.

We fully agree with Fortescue and Pratt that the treatment of harmonic quantities separately is often necessary and that the lumping of the effects of the harmonics, as our definitions contemplate, is not always a suitable procedure. While the terminology of our paper was primarily devised for those cases where lumping is permissible, yet it also is entirely consistent with the terminology required for a complete analysis. For example, a definite meaning is assigned to "the reactive power of the *n*th harmonic."

A number of the critics wished that we had decided upon a single definition for "apparent power" in unbalanced polyphase circuits. Pratt, J. J. Smith, and H. B. Smith favor "limiting apparent power," while others, including some who gave oral discussion at the convention, have not expressed a preference. Kennelly seems to think that the concept of "apparent power" is of little value, since he stresses the importance of vector power. It seems to us that the selection, at the present time, of a single definition is not possible, and perhaps will never be desirable. The various names represent different concepts, and until usage has demonstrated the ones that are useful, all of them should have distinguishing names and precise definitions. We believe it would be very unwise for the A. S. A. committee on definitions to fail to provide suitable names and definitions for quantities which are now in use.

As regards the names of the various concepts, the discussion brings out again the wide divergence of usage and opinion as to the best nomenclature. We feel that this is an indication that in the absence of some central agreement, usage is going to drift further apart and the present confusion become doubly confounded. The desirability of fixing some system of nomenclature seems greater than ever and the impossibility of satisfying everyone is obvious. It is interesting to note that both H. B. Smith and Sommerman suggest more systematic sets of names. We attempted this procedure and, in the pref-

erential ballot, suggested the same set as that now proposed independently by Sommerman. The returns, however, did not seem to favor such a scheme and only the name "nonreactive" met with favor.

The suggestion that the unit of each of these quantities should possess a specific name (distortion volt-ampere, etc.) indicating by an appropriate adjective the nature of the quantity of which it was a unit, seemed a logical extension of the accepted unit "var" for "reactive power." Brylinski was the only critic to object to this extension. His objection was unexpected because he has been active in stimulating the International Electrotechnical Commission to introduce the var, which is an abbreviation for the French expression "volt ampère réactive."

Budeanu's statement to the effect that the definitions in their present form are not sufficiently explicit as to the algebraic sign or direction of active and reactive power is well taken and we trust that these definitions will be supplemented to meet this criticism.

H. B. Smith and Pratt seem to feel that our use of the word "vector" and of the geometrical power diagram imply that we consider all power quantities to be physical vectors. We regret that the paper contains this implication and would emphasize here that the diagram in 3 dimensions is only a convenient method of representing some of the relations among the quantities concerned.

The numerical examples which are presented by Lyon, showing the differences in the various kinds of apparent power, are very interesting and show clearly the confusion which is to be expected if all of these quantities were labeled indiscriminately "apparent power."

The very different point of view of Quade in generalizing the definitions of these power quantities is very interesting and deserving of careful consideration. We feel, however, that his concepts differ so much from those underlying our definitions that a comparison of them is beyond the scope of this paper.

Calculations for Coreless Induction Furnaces

Discussion and authors' closure of a paper by H. B. Dwight and M. M. Bagai published in the March 1935 issue, pages 312–15, and presented for oral discussion at the electrochemistry and electrometallurgy session of the summer convention, Ithaca, N. Y., June 28, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): A very interesting development in connection with induction furnaces has been carried on recently in Germany. Figure 1 of this discussion shows such a furnace. Three coils, X, Y, and Z, are fed by 3 phase current and used in connection with a laminated iron ring A on the outside of the furnace. In this furnace, a rotating field is set up, causing a slow rotating motion of the metal bath; in addition, however, there are strong vertical currents in opposite directions in 3 regions of the bath. Aside from the fact that this furnace can be operated from line frequency it has, from a metallurgical and process point of view, the advantage of a larger bath surface with less depth, better durability of lining, and substantially increased speed of reaction by heating the slag to a higher temperature. The particular stirring action present entraps and emulsifies a considerable quantity of slag very effectively.

The electromagnetic conditions in such a furnace are, of course, quite different from those of the type of furnace discussed in the paper, and this new development is mentioned only for the purpose of emphasizing the necessity on the part of the electrical engineer to give most careful attention to the requirements of the process to be performed. It is quite evident that this particular furnace construction does not lend itself very readily to exact calculations on account of the complicated path of the secondary current, but this is of secondary importance if advantages from a process point of view can be obtained. These remarks are not intended to detract from the value of the work given in the paper and some of the subsequent discussion, as treatments of this nature are of interest not only in connection with certain furnaces that are in practical use but also with reference to a number of other problems met with in electrical engineering.

C. A. Adams (Harvard University, Cambridge, Mass.): Since the authors point out the superiority of their method over that method which employs penetration depth and the power transformer analogy, it may be assumed that they include the paper "High Frequency Induction Furnaces," by C. A. Adams, J. C. Hodge, and M. H. MacKusick, published in ELECTRICAL ENGINEERING for January 1934, pages 194–205.

The merit of any particular method of analysis lies in 3 factors: (1) the soundness of method and accuracy of result; (2) its relative ease of application; and (3) the relative simplicity and usefulness of the visual picture accompanying or associated with the method.

In problems of design it is also very important that the method be such as to express as simply and clearly as possible the connections between the several variables involved and the performance of the resulting structure.

The method of analysis presented in this paper meets none of these specifications.

The formulas as given in this paper are practically useless for application to coreless induction furnaces because of the complete neglect of the "end effect," which involves an error vastly larger than the difference between the 2 methods under discussion.

As a matter of fact, the authors themselves have proved in the example at the end of the paper that the penetration formula yields the same secondary resistance as that obtained by the employment of Bessel functions. Unfortunately, the same symbol, R_{eff}, is employed for the total effective resistance, primary and secondary, in the Bessel functions solution, as for the secondary resistance only as obtained by the penetration formula. It seems obvious that their reasoning led the authors to deceive themselves on this point, and may confuse the superficial reader.

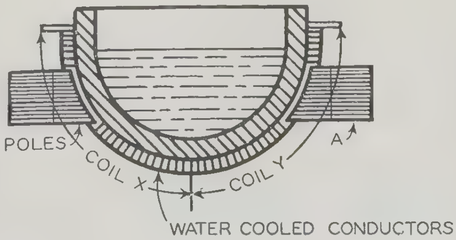
It is thus obvious that for high frequency induction furnaces, the error due to the employment of the penetration or skin depth approximation is absolutely negligible. Indeed, it is practically negligible in the case of 60 cycle furnaces of commercial sizes. This conclusion was reached by the writer many years ago after a careful comparison of the results obtained by both methods.

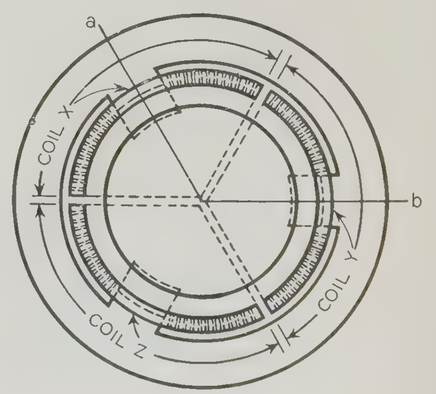
The real problem in the design of coreless induction furnaces is a proper evaluation of the "end effect." This evaluation was originally made by the writer on the basis of the end reluctance of solenoids, taking account of the fact that the secondary flux linking with the charge current is of much lower density than the leakage flux between primary and secondary. The coefficients thus obtained on a theoretical basis and given in the appendix of his paper have been used successfully ever since, in the design of numerous induction furnaces operating at frequencies varying from 60 cycles to 2,000 cycles.

It is, of course, entirely possible to take account of the "end effect" when using the Bessel functions method of analysis, but it is a much more difficult process and gives nothing like as clear a picture of the phenomenon involved. This was done in a very scholarly fashion by Burch and Davis (reference 1 of the paper) who took account of the boundary conditions which were not mentioned by the authors of the present paper.

The fact is that from the scientific point of view, the most exact method possible involves crude approximations. It is only when the problem is reduced to its simple elementary form, by assuming the length of the furnace very large as compared with its diameter, that the formulas given

Fig. 1. Plan and section through a–b of a type of induction electric furnace





y the authors of this paper yield results of ny value; and then it is not a practical nduction furnace.

Referring to the example at the end of the paper, the authors compute the power factor as 0.098. It happens that the writer has designed and built several furnaces of approximately the same dimensions, for which the power factor by calculation as well as by experimental test was between 0.11 and 0.13, depending upon the thickness of the lining. The authors' error is due to the complete neglect of the "end effect."

To sum up, the authors have presented a method of analysis for coreless induction furnaces which they claim to be more exact than that which employs the skin depth approximation. They appear to have proved that the effective resistance as calculated by the Bessel functions method is about 10 per cent larger than that calculated by the skin depth approximation, whereas their own calculations show that the effective secondary resistance is exactly the same (0.0281) to the third significant figure when calculated by the 2 methods, which is the only check comparison they made. Moreover, their calculation of power factor for a particular case is in error by approximately 20 per cent.

H. Poritsky (nonmember; General Electric Company, Schenectady, N. Y.): In this paper the authors present anew the Bessel function solution for the field and eddy currents of an infinitely long solenoid and core, and call attention to the power series and asymptotic expansions of the Bessel functions and to tables of these. The concise treatment, along with the examples presented, certainly renders this solution more accessible to engineers and induction furnace designers.

In the writer's opinion, however, the limitations on the applicability of the solution in question to actual furnaces have not been stated sufficiently clearly. Thus, a furnace is often designed of a height equal to the diameter, in which case the end corrections due to the flux penetration over the top and bottom and to the reluctance of the return path for the flux become fully as important as the discrepancy between the simple penetration formula and the Besels function solution applying to an infinitely long solenoid. In such a case, obviously either one is only an approximation.

It is highly instructive to derive the first term of equations 11 to 14 directly by supposing that the region in which the flux penetration is at all appreciable (the depth of penetration) is small compared to the diameter of the charge so that the curvature of the cylindrical surface can be neglected and be replaced by a plane. The problem then may be treated by means of rectangular co-ordinates, and the solution may be found in terms of exponentials. For the beginner, this has the advantage of avoiding the use of Bessel functions; this allows him to concentrate on the physics of the phenomena.

Let the direction normal to the plane boundary be taken as the y axis, and the direction of the positive current in the winding as the z axis, while the x axis coincides in direction with the former axis of the cylinder. From the former symmetry of the field, it will be recognized that all the field components but H_x and E_z vanish, and that these are independent of x and z. Maxwell's equations for this case become (in practical cgs units)

$$\frac{\partial H_x}{\partial y} = 0.4\pi\, I_z$$

$$\frac{\partial E_z}{\partial y} = -10^{-8}\frac{\partial B_x}{\partial t}$$

and replacing I by λE ($\lambda =$ conductivity $= 1/\rho$) and B by μH,

$$\frac{\partial H_x}{\partial y} = 0.4\pi\lambda E_z$$

$$\frac{\partial E_z}{\partial y} = -10^{-8}\mu\frac{\partial H_x}{\partial t}$$

Eliminating either E_z or H_x shows that either one satisfies the equation

$$\frac{\partial u}{\partial t} = k\frac{\partial^2 u}{\partial y^2} \quad k = 4\pi\, 10^{-9}\lambda\mu$$

This will be recognized as the equation of heat conduction and can be made the basis of a useful analogy which would show that the flux penetration for the case of a magnetic field whose surface value varies sinusoidally is similar to the temperature penetration, say into a solid earth as the result of periodic variations of surface temperature.

Suppose, in fact, that at the boundary $y = 0$, H_x has the value

$$H_x = A\cos\omega t$$

It is proper to assume that the field components everywhere vary sinusoidally, though not necessarily in phase with each other. Mathematically, it turns out to be simplest to replace the boundary condition by

$$H_x = A\,\epsilon^{j\omega t} \text{ at } y = 0$$

and to assume that time enters everywhere as a factor $\epsilon^{j\omega t}$. The actual real field is obtained by taking the real part of the complex solution, and in fact the (complex) coefficients of $\epsilon^{j\omega t}$ yield the familiar representation of sinusoidal quantities by means of vectors. If the factor $\epsilon^{j\omega t}$ is omitted, the differential equations become

$$\frac{dH_x}{dy} = 0.4\pi\lambda E_z \qquad \frac{dE_z}{dy} = -10^{-8}\, j\mu\omega H_x$$

and eliminating, there is obtained for either H_x, or E_z

$$\frac{d^2u}{dy^2} = \alpha^2 u \qquad \alpha^2 = j\, 4\pi\omega\lambda\mu 10^{-9}$$

Since α^2 is purely imaginary, α can be taken along the 45 degree direction

$$\alpha = (1 + j)\beta$$
$$\beta = \sqrt{2\pi\omega\lambda\mu 10^{-9}} = 2\pi\sqrt{f\lambda\mu 10^{-9}}$$

where f is the frequency. There are obtained for the solutions linear combinations of

$$\epsilon^{-\alpha y},\ \epsilon^{\alpha y}$$

but imposing the condition that the field does not become infinite for $y = \infty$,

$$H_x = A\,\epsilon^{-\alpha y} = A\,\epsilon^{-\beta y}\,\epsilon^{-j\beta y}$$

From this, it may be seen that the amplitude decreases exponentially while the phase advances uniformly. Defining the depth within which the amplitude becomes $1/\epsilon$ of its boundary value as the depth of penetration d,

$$d = 1/\beta = 1/2\pi\sqrt{\frac{\rho 10^{-9}}{f\mu}}$$

If the radius of the solenoid core is substantially greater than d, the results of this treatment will apply very nearly. Similar solutions obtain for E_z and for the eddy current amplitude I_z. It is found that

$$E_z = \frac{A}{0.4\pi\lambda}\,\epsilon^{-\alpha y}$$

At $y = 0$ the primary current may be supposed to be spread over a thin sheet of current density i per unit x (yet insulated from the conductor). The magnetomotive force relation applied to both sides of $y = 0$ yields

$$H_x\Big|_{0+} - H_x\Big|_{0-} = 0.4\pi\, i$$

where the subscripts $0+$, $0-$ refer to the positive and negative sides of $y = 0$. For an infinitely long solenoid, it may be recognized that the field vanishes on the outside, the magnetomotive force being consumed entirely on the inside. Hence, $H_x\big|_{0-}$ is put equal to zero, and there is obtained

$$H_x\Big|_{0+} = A = -0.4\pi i$$

and substituting above, there is had a complete expression for the magnetic and electric field,

$$H_x = -0.4\pi i\,\epsilon^{-\alpha y} \qquad E_z = -\frac{i\alpha}{\lambda}\,\epsilon^{-\alpha y}$$

while the eddy current density is given by

$$I_z = -i\alpha\,\epsilon^{-\alpha y}$$

The quantity $\alpha/\lambda = (1 + j)\, 2\pi\, 10^{-9}\mu f\rho$ is of importance and will be denoted by Z. Considering now the total or resultant current for the complete thickness of the conductor and per unit x,

$$\int_0^\infty I_z dy = -i\,\alpha\int_0^\infty \epsilon^{-\alpha y}\,dy = -i$$

Thus, the resultant eddy current is equal to the primary current but is opposite in phase. This conclusion is obvious physically from the fact that to shield the bulk of the conductor from magnetic field penetration, a skin current must be developed that opposes the primary current.

Consider next the question of losses. While one could obtain this by integrating ρI^2 throughout the depth, it is easier to utilize the electric field value at $y = 0$. The vector $\boldsymbol{E}$ represents (in volts per centimeter) the *induced electric* field that the primary will have to overcome. The actual field existing in the primary is thus $E_{appl} + E$ in volts per centimeter, where E_{appl} refers to the applied field. For simplicity suppose there is one turn per centimeter and let R_p be the resistance of the primary per unit length. Then the primary current is given by

$$i\,R_p = E_{appl} + E$$

or replacing E by its value previously found,

$$i\,R_p = E_{appl} - i\frac{\alpha}{\lambda} = E_{appl} - Zi$$

whence

$$E_{appl} = i\,(R_p + Z)$$

so that the net effect of the presence of the secondary is as if an impedance Z were put in series with the primary.

If there are n turns per unit height, then the magnetic field is multiplied by n; likewise for the electric field. In counting the induced electromotive force a further multiplication by n is encountered since each one of the n turns meets the induced field. The equivalent impedance of the secondary per unit area is thus

$$n^2Z = n^2(1 + j)\,2\pi\sqrt{10^{-9}\mu f\rho}$$

The total flux ϕ in the secondary per unit length of the coil can be found by integrating $\int_0^\infty \mu H_x dy$, and the induced field can then also be obtained from $10^{-8}\,j\omega\phi$.

The above treatment of eddy currents has been used to advantage in the advanced course in engineering of the General Electric Company and found to induce a clearer picture of the physics of eddy currents than the one retained by the students from their college courses.

H. B. Dwight and **M. M. Bagai:** The discussion by C. A. Adams deals with 2 separate features: first, the use of the penetration formula; and second, the "end effect," that is, the change in the results caused by assuming that conditions are uniform along the axis and therefore that the magnetic flux is in straight lines.

It is stated in the paper, following equation 19, that the penetration formula gives the resistance with slide rule accuracy for ma = 6 or larger. In the example illustrated, ma = 14.1, and the effective resistance of the secondary is shown to be 0.0281 by both formulas. Where R_{eff} means the resistance of the secondary only, it is plainly stated, and there is really no reason for even a casual reader to become confused in this matter.

If, due to high resistivity of the charge, small diameter, or low frequency, ma is less than about 6, the penetration formula is inapplicable for calculating the secondary resistance. If it is desired to plot the current density or heating density throughout the molten charge, as is done in figure 2 of the paper, or if it is desired to plot the flux density in the charge, the calculation based on a certain depth of uniform penetration is inapplicable no matter how large ma may be.

Adams does not seem to have given in his paper or in his discussion a justification for multiplying a uniform flux density by the area of the cross section of the furnace, when the effects are proportional to the perimeter instead of the area of the circle, as is well known in connection with high-frequency skin-effect problems.

The use of Bessel functions in electrical skin effect problems is practically as straightforward as the use of sines and cosines, and there should be no reluctance to using them merely because of their supposed difficulty.

In connection with the end effect, both H. Poritsky and Adams mention the ratio of the length to the diameter. The magnetic flux, however, is substantially confined between the primary and secondary, and so the ratio which decides the importance of end effect is that of the length to the distance between primary and secondary. This is a much larger ratio and indicates a closer approach to the condition of straight line flux.

A similar condition occurs in power transformers, where good agreement between calculation and test is obtained in computing reactance by assuming straight line flux, that is, neglecting end effect.

It is not implied that end effect is negligible nor as small as in transformers. Our paper makes no estimate of how important end effect may be. It is, however, proper to discuss the main calculation before taking up the corrections. It is to be noted that the basis of the calculation in our paper is the same in this regard, as that of Poritsky's discussion. If Adams has a method of calculation for end effect, it can be discussed if and when it is published showing how his final results and constants were obtained.

It is probable that the computation of end effect in this skin effect problem will require some simplifying assumptions, and it will be desirable to check the results by tests, or to use test results in designing. Such tests should not be made on practical furnaces because of the great uncertainty in the value of resistivity of the molten charge and of the effective resistance of the primary winding, composed as it is of large conductors. A copper model would be better for making such tests, and could be constructed as follows:

A number of heavy copper rings could be made, about 8 or 9 inches in diameter and of cross section about $^5/_8$ inch radially by 2 inches axially, the joint being carefully made so as to have as low resistance as possible, preferably making the resistance practically uniform around the ring. The rings should be machined so as to be true circles. If they are placed along the same axis and touching each other, they form a cylinder which at 60 cycles has the same proportions, electrically, as an electric furnace. The primary can be wound with a sufficiently small conductor that it will have practically no skin effect at 60 cycles. Several primary windings can be made easily of different diameters and lengths, and in this way the end effect and the agreement between calculation and test can be determined accurately for various ratios of length to distance between primary and secondary, and for various differences between the lengths of primary and secondary. The number of sections used to make up the secondary can be changed as desired.

An alternative method of making the short-circuited secondary would be to wind it of square wire of about $^1/_2$ inch diameter and then carry one end of the wire axially through the coil to be fastened to the other end in a long joint of large contact surface.

The calculation for this model will be the Bessel function solution for a tubular secondary, which has been recently published by N. W. McLachlan. This, if expressed in series form, has the first part the same as the penetration formula. The determination of the end effect practically will not be influenced by the tubular shape of the secondary.

The number of primary turns can be made sufficient so that the voltage will be large enough, and the current small enough, to be measured with ordinary instruments, and thus the usual difficulty of making skin effect measurements at 60 cycles will be avoided, namely, that of extremely large currents and small voltages.

It is to be noted that the principle of similitude is used here to allow the use of a model of lower frequency than that of the original apparatus. A 60 cycle model is proposed instead of a high frequency model because the 2 parallel layers of winding have capacitance which, unless the frequency is very low, is likely to interfere with the measurement of the effective resistance and reactance.

The same model can be used to check formulas for skin effect loss in transformer windings, and to make this more complete, heavy square wire secondaries with 2 or more layers in series or in parallel may be used. This, in turn, will provide a partial check on similar formulas used for generators, not all of which are in exact agreement.

Photoelectric Control of Resistance Type Metal Heaters

Discussion and authors' closure of a paper by E. H. Vedder and M. S. Evans published in the June 1935 issue, pages 645–50, and presented for oral discussion at the electrochemistry and electrometallurgy session of the summer convention, Ithaca, N. Y., June 28, 1935.

W. R. King (nonmember; General Electric Company, Schenectady, N. Y.): This paper is very interesting to me because I have done a great deal of work on both the theoretical and practical aspects of the application of photoelectric equipment to temperature measurement and control.

One of the principal theoretical considerations is, of course, the relation between the temperature of the hot body and the photoelectric tube response, and I find that my data on this relation does not check with that of the authors as represented in figure 7 of the paper. I find an even steeper relation between temperature and tube current. In obtaining my data I used tubes having a spectral characteristic almost identical to that shown by the authors, and I have obtained an excellent correspondence between theoretical calculations and test results. In my tests, however, I used a vacuum photoelectric tube operating above saturation, and I believe the discrepancy between my data and the authors' figure 7 could be accounted for if their data are based on a gas filled tube, since the change in voltage drop across the series resistor would then tend to make the temperature-current curve less steep. I should like to have the authors comments on this point.

I note that figure 14 shows a definite calibration of the adjustment potentiometer

to cause the control unit to operate at different temperatures for various bar sizes, and would like to know if some additional adjustment is provided to accommodate tubes of different sensitivities within the usual manufacturing limits, or if the limits have to be narrowed for this particular application. If selected tubes are used, is the selection based upon over-all sensitivity or upon a combination of over-all and spectral sensitivities?

My experience on the lower limit of operating temperature for the photoelectric pyrometer agrees very well with that of the authors.

I believe that further emphasis should be placed on the fact that the relation between temperature and tube response is so steep that ordinary variations in tube sensitivity will have little effect on the accuracy. For example, at temperatures of about 2,000 degrees Fahrenheit, a 10 per cent change in tube sensitivity would produce an error of only about 20 degrees Fahrenheit. For a vacuum photoelectric tube, a 10 per cent change in sensitivity is about the maximum that would be expected over a long period.

The tube circuit used in the control unit described by the authors incorporates one feature which has been found to be extremely important in using grid-controlled gas-filled tubes as on-off relays in a-c circuits, namely, the leading alternating grid voltage component which makes the tube start to conduct at an early point in the cycle.

Our experience in attempting to use 3-electrode grid-controlled gas-filled tubes controlled directly by a high impedance photoelectric tube circuit, however, has not been so successful. We have found that the control characteristics are impaired by the grid current of the gas filled tube. This trouble has been largely overcome by the development of 4-electrode tubes in which the control grid current is extremely low, but I would be interested in the authors' comments on this point.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper dealing with an electrical process and a method of regulating it, should be of interest to many industrial engineers other than those in the fields of electrochemistry and electrometallurgy. As a matter of fact, the process involved finds its principal application in what is broadly termed the "metal working" industries, including, for instance, the automobile, structural steel, and many others. There are many electrical processes, such as arc, spot, seam, and butt welding; heat treating of metals and other materials; drying; and so forth. There are also a great many instances in industry where the metering and the regulating of all kinds of electrical and nonelectrical processes can be accomplished by electrical means.

After the motorizing of industry by means of the electrical motor had become a matter of course, many of us had hoped that these electrical processes and the metering and regulation of them by means of electrical devices would show considerable growth; however, the progress on the whole has been disappointingly slow, though a few items such as arc welding have made considerable headway in the last few years. One of the difficulties apparently is that the engineering societies, such as the A.I.E.E., have not found the best way to bring the various interested parties together or to stimulate sufficient interest in these matters.

This paper and the discussions present possibilities and limitations of electrical means in a fundamental way as influenced both by the characteristics existing in light sensitive tubes and by the process to be handled. It is only by presenting these matters fundamentally and, as has been done in the paper, indicating, for instance, the limits imposed by the radiating energy available and also the limits of the electron device, that the application engineer will be enabled to attack his problems properly and the designers to take steps to broaden the working range of their equipment. Similar conditions were indicated in connection with another paper on the coreless type induction furnace presented before this session. While the paper itself dealt with rather intricate electrical problems, the brief discussion (p. 187) that I contributed shows how these problems are tied up with metallurgical problems, especially those relating to the proper stirring of the metal bath. Without the presentation of such fundamentals before meetings attended by the various groups of interested engineers, matters of great importance are likely to be overlooked by some of the groups, which, of course, will retard progress. In further considering this subject of processes, it should be realized that many processes that have been found advantageous in one industry can also be used to advantage in many other industries if the fundamentals involved are brought to the attention of the various industries.

All of this indicates not only that this entire subject should be actively sponsored, but also that it perhaps should be organized on a somewhat broader scale and possibly handled by a committee whose activities embrace all kinds of electrical industrial processes (other than motorizing) and electrical methods of regulating and metering processes, rather than by the presentation of such material before sections dealing with specific industries or specific types of processes.

E. H. Vedder and **M. S. Evans:** The data presented on the relation between photoelectric tube response and temperature of the hot body probably differs from that taken by W. R. King for the reason he suggests, since the authors' data were taken with a gas filled tube.

The curve shown in figure 14 is given only as typical and is not strictly a calibration since the setting for a given temperature depends on various factors such as the radiating ability of the various materials, tube sensitivity, initial optical adjustment, and maintenance of optical efficiency. This device described may be called a photoelectric limit switch whose initial adjustment is made using an optical pyrometer as a standard. Thus, tube sensitivity is compensated for in the initial adjustment, and tubes with standard manufacturing tolerances may be used satisfactorily.

The authors' experiences with 3-electrode grid-controlled tubes indicate that properly designed tubes of this type operate very successfully in circuits having grid impedances of 10 megohms or more. This experience has been acquired over a period of about 3 years using this same type of circuit in a variety of photoelectric control applications.

Storage Battery Charging

Discussion and author's closure of a paper by J. L. Woodbridge published in the May 1935 issue, pages 516–25, and presented for oral discussion at the electrochemistry and electrometallurgy session of the summer convention, Ithaca, N. Y., June 28, 1935.

G. W. Vinal (Bureau of Standards, Washington, D. C.): In the opening paragraph of this paper, the author mentions the chemical reactions in the lead storage battery as the subject of some controversy. He points out, however, that the "double sulphate" theory, originally proposed by Gladstone and Tribe, is now generally accepted. The validity of this theory has often been questioned because of disagreement between the theory and certain experimental results. If the equation representing the theory is true, the passage of one faraday of electricity in the direction of discharge should result in the consumption of one equivalent each of lead and lead dioxide and 2 equivalents of sulphuric acid, while 2 equivalents each of lead sulphate and water are formed. Numerous experiments to determine the relationship between the quantity of electricity passing through the cell and the materials formed or consumed are recorded in the technical literature. Most of these experiments relate to determinations of the number of equivalents of acid taking part in the reaction. Results previously obtained have varied through wide limits, probably because of experimental difficulties in determining exactly the quantity of electrolyte within the cell.

Within the past year, experiments at the National Bureau of Standards have been made, employing the "method of mixtures" for determining the amount of acid in the cell, both at the beginning and end of discharge. This method has not been previously applied to this particular problem so far as the writer is aware. It has many advantages for the purpose and has enabled the determination of not only the number of equivalents of acid used per faraday, but also the number of equivalents of water formed. As a result of 9 discharges, the mean value of the equivalents of acid per faraday was found to be 2.02 ± 0.03 as compared with 2.00 equivalents demanded by theory. Since these determinations were based upon the weight and percentage strength of the electrolyte at both the beginning and end of each discharge, sufficient data were provided to calculate directly the amount of acid consumed and water formed as a result of reaction. No assumptions regarding the correctness or applicability of any theory of chemical reactions in the battery were necessary therefore in computing the number of equivalents taking part in the reaction. The writer knows of no previous attempt to de-

termine the amount of water formed by the process of discharge nor of calculations of the acid consumed which are thus independent of theoretical assumptions.

The amount of water formed is a small part of the change in weight of the electrolyte and determinations must therefore be made with the greatest care, if direct calculations of the water are to be sufficiently precise to be valuable. In the course of the work, it was found that evaporation from the cell was a serious source of error. In the last 4 experiments, therefore, precautions were taken to avoid evaporation. The mean result of these last experiments shows that 1.96 ± 0.19 equivalents of water were formed per faraday as compared with 2.00 demanded by the theory. The results of this work are therefore entirely consistent with the double sulphate theory. This work has recently been published in the *Journal of Research* of the National Bureau of Standards, volume 14, 1935, pages 449–62.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The paper has discussed in detail certain losses which are caused by gassing during the charging of a battery as a result of improper control of the charging rate. Later on certain arrangements are given which introduce resistors for the purpose of bringing about the proper charging rate. The losses in these resistors will reduce, if not eliminate, any gains made by bringing about the proper charging rate. It would be interesting to know the magnitude of the losses caused by such resistors. I am also wondering whether the maintenance of the proper charging rate is perhaps not more important in connection with obtaining the best results in the way of maintenance, attendance, and battery life than it is from a loss point of view.

Only brief reference is made in the paper to applications where the charging is accomplished from an a-c source through a rectifying arrangement. In such a case there are various possibilities of regulation on the a-c side, without any necessity for resistance losses. With these a-c arrangements constant-current characteristics can be obtained without much complication where desirable. However, in view of the conditions indicated in figures 2 and 3 of the paper, which indicate definitely the advantage of constant voltage charging, it is surprising that most of the practical arrangements for alternating current are designed for constant-current characteristics. As there must be an appreciable number of applications where an a-c system is used as the charging source, it would be interesting to have the author's comments regarding the desirability of designing such equipments for constant voltage charging, or perhaps for 2-voltage charging, wherever possible.

J. L. Woodbridge: The investigations reported by G. W. Vinal in respect to the "double sulphate" theory of the reactions in the lead storage battery cell are certainly interesting and important, and will undoubtedly serve to settle this long standing controversy.

In reply to R. E. Hellmund's remarks comparing the losses in the battery due to improper charging with those introduced by resistors for controlling the charging rate, it must be evident that, assuming the same voltage at the charging source, any reduction in the total ampere hours delivered to the battery resulting from improved charge control must effect a net reduction in the total energy taken from the source. He is quite correct, however, in his suggestion that the improvement in battery life and maintenance resulting from better charging conditions is usually more important than the saving in energy.

In respect to installations in which the battery is charged from an a-c source through a rectifier, it is quite true that in many of these cases constant current is employed, but usually the rate is so low that nothing would be gained by constant voltage control. Even where the charging time is limited and higher rates are therefore required during the early stages, the 2 step method is nearly as satisfactory as constant voltage control and usually simpler, especially where the charging current is obtained from an a-c source through a rectifier, and initial overload protection for the charging apparatus must be provided.

Control on the a-c side of the rectifier is sometimes employed, with some saving in energy, but this saving is often more than offset by the added complication of the control apparatus required.

It is also to be noted that in strictly standby service, while efficiency of the floating or trickle charge is important, the effect of some departure from ideal conditions in recharging after the usually very infrequent emergency discharges is comparatively insignificant and should be subordinated to simplicity and reliability.

The Determination of Circuit Recovery Rates

Discussion of a paper by E. W. Boehne published in the May 1935 issue, pages 530–9, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935.

Joseph Slepian (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The importance of the natural free oscillation of the circuit in which a breaker is placed in determining breaker performance seems to have been first pointed out in my paper "Extinction of an A-C Arc" (A.I.E.E. Trans., v. 47, 1928, p. 1398–1407). In this paper is given the equivalent of figure 1 of the present paper. Also, the circuit recovery rate is calculated for laboratory circuits containing resistance. In a following paper, "Extinction of a Long A-C Arc" (A.I.E.E. Trans., v. 49, 1930, p. 421–30) was first given the now widely used description of arc extinction at current zero as being determined by the outcome of a kind of race between 2 factors, one tending to reignite the arc and described by the voltage recovery characteristic of the circuit, and the other opposing arc reignition, and described by the rate of recovery of dielectric strength of the arc space after current zero. In this paper it was stated that the first factor could be calculated, in theory at least, from the constants of the circuit by well-known principles of electrical engineering, but the second factor required experimental and theoretical research into the nature of an a-c arc at current zero, of which a beginning was made in this and the preceding paper.

The calculation of the first factor by the known principles of electrical engineering was then gratifyingly carried out by R. H. Park and W. F. Skeats (A.I.E.E. Trans., v. 50, Mar. 1931, p. 204–38) and further refined and verified by the cathode ray oscillograph by Poitras and Kuehni, Van Sickle, and other investigators both here and abroad. The present paper by Boehne is a very valuable addition to this literature and with the charts given, and the new concept of recovery impedance, makes the calculation of the numerical quantity "circuit recovery rate" quite easy.

However, the importance of the circuit recovery characteristic depends entirely on its relation to the dielectric recovery characteristic of the arc space, and the increased knowledge which we now have of this latter characteristic in practical circuit breakers coming from researches of Westinghouse engineers, and Kesselring and his associates at Siemens-Shuckert, and Mayr and his associates at Allgemeine Elektricitaets Gesellschaft has wholly changed our ideas as to what are the important elements in the circuit recovery characteristic. We now know that the numerical circuit recovery rate. given in volts per microsecond is not an important quantity, and that with 60 cycle current this numerical circuit recovery rate may be infinite, and still not impose severe duty upon the circuit breaker. With the numerical voltage recovery rate reduced to unimportance, the recovery impedance of Boehne which enables the numerical voltage recovery rate to be calculated easily, also loses some of its significance.

These conclusions follow from the fact that for all types of practical 60-cycle a-c circuit breakers the dielectric recovery characteristic of the arc space has been found to be of the form shown in figure 1 of this discussion. This was shown to be the case for short arcs in my papers on arc extinction referred to in this discussion. Biermann (Elektrotechnische Zeitschrift, v. 50, 1929) found such a characteristic for oil breakers. T. E. Browne, Jr. (A.I.E.E. Trans., v. 51, Mar. 1932, p. 189) gives a similar characteristic for an expulsion fuse. D. C. Prince and W. F. Skeats (A.I.E.E. Trans., v. 50,

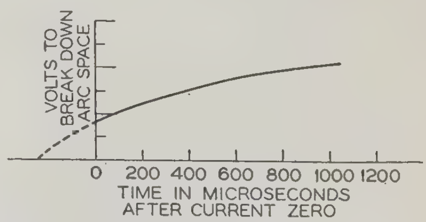


Fig. 1. Dielectric recovery characteristic of circuit breakers

June 1931, p. 511, figure 11) give data on oil breakers both of the oil blast and ordinary type which correspond to this type of characteristic, as Browne has brought out in his discussion (A.I.E.E. Trans., v. 51, Mar. 1932, p. 193).

It is clear that if as in figure 1 of this discussion the arc space at current zero already has considerable dielectric strength, the immediate rate of rise of recovery voltage of the circuit is of no consequence. Furthermore, we see that the gain in dielectric strength of the arc space is considerable only after a hundred or more microseconds after current zero. The strong dependence of circuit breaker performance on circuit characteristics often observed always referred to circuits having recovery times differing by several hundred microseconds.

Whether the circuit recovery rate is 2,500 volts per microsecond or 5,000 volts per microsecond is not important for the circuit breaker, but the circuit recovery time, that is, whether the maximum circuit voltage is reached in 200 microseconds or 100 microseconds, is important. Furthermore, the circuit recovery times are important if they are long, but if they are short, their actual magnitude does not matter much. Thus, from figure 1 of this discussion, if it is short, it makes little difference whether the circuit time is 20 microseconds, 10 microseconds, or even 0 microseconds.

The universal appearance of a characteristic of the type of figure 1 in the most varied kinds of 60 cycle arcs has led me to believe that the arc space begins to develop dielectric strength several hundred microseconds before current zero as indicated by the dotted curve in the figure, although in oscillograms this dielectric strength is concealed by a large but rapidly decreasing electrical leakage. This view is developed in my paper in Elektrotechnik und Maschinenbau (v. 51, heft 14–15, 1933, p. 180) where experimental evidence is given supporting it. Kesselring, I believe, also independently arrived at this conclusion, and in a recent most admirable paper (Kesselring and Koppelmann, Archiv für Electrotechnik, v. 23, heft 1, Jan. 11, 1935) has refined and elevated the idea and gives it a sound theoretical foundation.

The race between the circuit recovery voltage and the arc space dielectric recovery is then not one from scratch, but the arc space has a start of several hundred microseconds. Giving the numerical circuit voltage recovery rate will then not determine the outcome of this race, but the circuit voltage recovery time is a more significant number.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The recovery characteristics of electrical circuits are of general interest because they have a bearing on the performance not only of circuit breakers but also of fuse interrupters and deionizing lightning protectors. I consider this paper and that by R. C. Van Sickle both excellent ones which supplement each other. Boehne has approached his subject from the theoretical point of view and organized his results in a convenient form for general use. Van Sickle has attacked the problem more from the experimental point of view by means of cathode ray oscillograms on circuits which had been calibrated as regards natural periods, reactance, and capacity. He had found that formulas published prior to his paper had been of no assistance in calibrating circuits as they did not agree with the experimental results. However, I understand that he has used Boehne's and has found that they are in agreement with the experimental data. Boehne states that his formulas check results obtained on tests of the circuit breakers for the Boulder Dam-Los Angeles transmission line. Both of them indicate what characteristic included in the circuit constants will reduce the recovery voltage rate and help the performance of the circuit breaker.

The impression obtained on reading these 2 papers is the importance of combining theory with experiment under controlled laboratory conditions. If under such conditions the calculated results do not agree within fair approximation with the experimental results, the theory can be modified until the approximation is satisfactory. In this way the theory can be checked under diverse circuit conditions and modified until it fits all of them.

I have thought of the problem of recovery voltage from a somewhat different angle of approach from Boehne. Consider an ideal circuit breaker as one having negligible arc drop and one in which deionization takes place instantly after the current reaches zero in one of the terminals, and ignore for the time being the capacitative constants of the generator and circuit up to the point of fault; then when current zero is reached after an ungrounded 3 phase purely inductive fault, if the positive sequence and negative sequence impedance of the circuit are the same, the system will become phase to phase faulted without discontinuity and the terminal voltage for this type of fault will appear instantly across the cleared contact terminals of the circuit breaker. Consider next this voltage as impressed at the terminals of the circuit with the capacitances now included, with the result that the voltage that will appear across the terminal of the circuit breaker will not be instantaneous but will build up from zero at a rate which will depend upon the complete constants of the circuit up to the circuit breaker, and the solution may be obtained by operational calculus or by the classical method of solution of the differential equations.

In the case of a 3 phase fault to ground when the interruption takes place at zero current, the resulting currents that are obtained in the other 2 terminals will not necessarily have the right value at that instant for a double phase-to-ground fault, because positive, negative, and zero sequence impedance may all be different. It appears to me that when the zero, positive, and negative sequence reactances are different, to obtain the theoretically correct results, the use of symmetrical components is indicated, but probably for practical work a simple compromise can be worked out that would be a close enough approximation, and this is apparently what Boehne has done.

L. V. Bewley (General Electric Co., Pittsfield, Mass.): On page 537 of his paper, the author mentions the advantage of resistors shunting current limiting reactors in reducing the recovery impedance. Such shunt resistors not only reduce the *rate of rise* of the recovery voltage, but also limit the *magnitude* of that rise. It is the object of this discussion to show an example of what may be realized with a shunt resistor in this respect. The theory and design of shunt resistors for reactors have been given elsewhere ("Shunt Resistors for Reactors" by Kierstead, Rorden, and Bewley, A.I.E.E. TRANS., v. 49, July 1930; and "Shunt Resistors for Reactors—II" by Kierstead and Bewley, ELEC. ENGG., Mar. 1934). In those papers it was shown that a constant resistance is out of the question, but that "thyrite," owing to its nonlinear characteristic, admirably fulfills the requirements. However, on account of its nonlinear characteristic, circuits involving this material usually have to be solved graphically or by a step-by-step method; and such is the case here.

Figure 2 of this discussion shows a current-limiting reactor on one of the feeders of a 13.8 kv system, the bus of which is assumed to be infinite with respect to the feeder rating. The breaker is interrupting a feeder fault on the feeder side of the reactor. The reactor has an inductance of 0.002 henry and therefore will limit the fault current to 10,600 amperes. A suitable shunt resistor for this reactor would be a stack of 10 thyrite disks, each 6 inches in

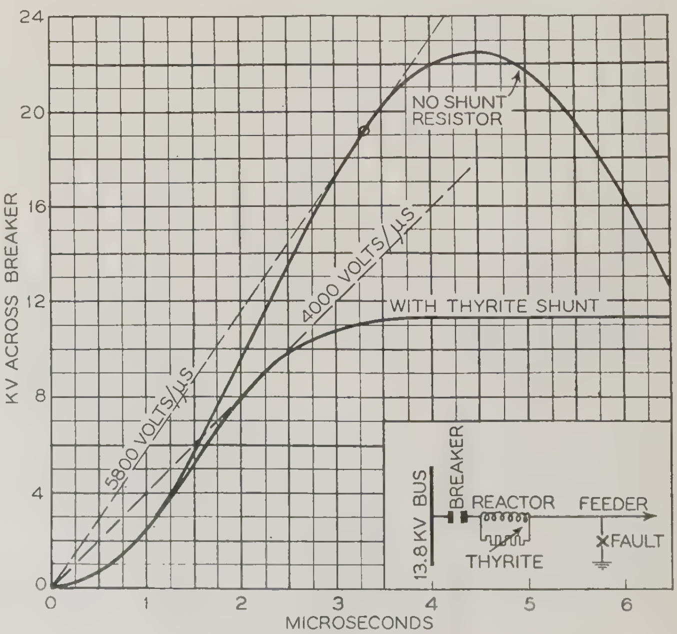


Fig. 2. Effect of using "thyrite" shunt across reactor

diameter by 3/4 inch thick, with a volt-ampere characteristic given by

$$e_T = 5800\ i^{0.28}$$

The effective capacitance to ground is taken as 0.001 microfarad. Then by equation 1 in Boehne's paper, the superimposed current at the instant of interruption is

$$i = \sqrt{2}I\omega t = \sqrt{2} \times 10{,}600 \times 377t = 5.66 \times 10^6 t$$

This current divides 3 ways: a part i_L through the reactor, a part i_C into the capacitor, and a part i_T through the thyrite. We then have the incremental equations

$$i_c = i - (i_L + i_T)$$

$$\Delta e = i_c \frac{\Delta t}{C}$$

$$e = \Sigma\ \Delta e$$

$$\Delta i_L = e_{avg.} \frac{\Delta t}{L}$$

$$i_L = \Sigma \Delta i_L$$

$$i_T = (e_T/5{,}800)^{3.57}$$

Herefrom the step-by-step process gives the recovery voltage shown in figure 2 of this discussion, having a rate of rise of 4,000 volts per microsecond, and the voltage across the breaker limited to normal system leg voltage (crest). This latter statement is easily verified as follows: a constant voltage condition is reached when the current through the reactor is increasing at the same rate as the superimposed current through the breaker, for then there is no further change of current in the capacitance or resistor. This condition is

$$L\frac{di}{dt} = L\frac{d}{dt}(\sqrt{2}I\omega t) = \sqrt{2}I\omega L = E\ (\text{crest})$$

Now if there is no thyrite shunt, the recovery voltage is

$$V_r = \sqrt{2}I\omega L\left(1 - \cos\frac{t}{\sqrt{LC}}\right) = 11{,}270\ (1 - \cos 40.5\ t)$$

reaching an ultimate value of $2E$ and a rate of rise of 5,800 volts per microsecond.

Thus the addition of the shunt reduces the rate of rise by 31 per cent and reduces the magnitude of the recovery voltage by 50 per cent, which are very substantial reductions.

D. C. Prince (General Electric Co., Philadelphia, Pa.): In considering ability to calculate accurately voltage recovery rates of circuits, it should not be forgotten that the problem is definitely in 2 parts: determination of circuit constants and calculation of recovery rate from circuit constants. All inaccuracies other than mistakes in arithmetic come under the first. The calculation may be laborious or very difficult where a complicated circuit is involved, but it is as exact as we care to make it.

In determining constants, inaccuracies are most likely to arise from simplifying assumptions, that is, distributed capacitance is regarded as lumped, etc. The distributed case is not impossible, but is usually not worth while. A circuit breaker should have an ample margin in handling recovery rate. It is, therefore, designed for relatively high values which are obtained from circuits of lumped reactance and little capacitance. A calculation of the 2 principal frequencies of a circuit, assuming the necessary lumping of the constants, is certainly sufficient to determine whether duty is severe and approximately how severe.

For the moment that is enough and is a great help along the way. There has been a tendency to look for one per cent accuracy where in many places the location of the decimal point was not known last year. It is hoped that a mass of approximate knowledge may be obtained from which the accuracy needs of the situation may later be determined.

R. C. Van Sickle (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper presents useful charts for the calculation of circuit voltage recovery characteristics. Having spent considerable time calibrating laboratory circuits, and having made occasional attempts to check the experimental data mathematically, I appreciate the curves and tables which he has prepared and published.

In the paper "Breaker Performance Studied by Cathode Ray Oscillograms" [Elec. Engg. (A.I.E.E. Trans.), Feb. 1935, p. 178–84] I presented in figure 2 experimental data taken to determine the natural frequencies of a 13.2 kv high power laboratory circuit, and stated that the data did not agree with published formulas. When Boehne published his charts I applied them to the experimental data and found that they gave results consistent with the data. The charts for the relative amplitudes of the 2 components show that the larger amplitude is associated with the lower frequency at both the highest and lowest currents. This indicated that the curves fitting the experimental data should have been drawn with the curve for the lower frequency passing through the data for low currents. With this change there is an agreement between the experimentally determined frequency curves, the results obtained using Boehne's charts, and the curves obtained from the formulas in *Report* 31 of the 1933 Conference Internationale des Grands Reseaux Electriques à Haute Tension. *Report* 31, however, does not contain information on the relative amplitudes associated with the 2 frequencies and suggests neglecting the higher frequency because of its more rapid damping.

For a discussion of the constants to be used for various types of faults, Boehne refers the reader to the paper by Park and Skeats. I believe it should be pointed out that the formulas given in that paper for the high frequency phenomena for the circuits corresponding to those discussed by him do not give results agreeing with his curves, and the approximate methods of proportioning the amplitude of the components give results which do not approximate those from his charts. Since Boehne's charts give results agreeing with the experimental data, they probably are based on new assumptions or additional refinements.

The term "recovery impedance" is introduced and called the accurate criterion for comparing one circuit with another independently of the current which is being interrupted. The reason for this statement is not given and is not apparent. The term is intended to refer to the ability of a circuit to oppose extinction of the arc. Since, for a given restored voltage, the breakdown of the arc space is dependent upon the rate at which voltage would appear across the contacts, the voltage recovery rate, or its equivalent, would appear to be a good criterion. The recovery impedance, however, is not directly proportional to this quantity. It is only one of the factors entering into the formula for voltage recovery rate, another factor being the current. Therefore, for circuits of different current values, the recovery impedance would not be proportional to the voltage recovery rate.

Since the constants of the circuit determine both the recovery impedance and the current, why not determine both factors and use the voltage recovery rate?

Oil Circuit Breaker and Voltage Recovery Tests

Discussion of a paper by E. J. Poitras, H. P. Kuehni, and W. F. Skeats published in the February 1935 issue, pages 170–8, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935.

H. P. Kuehni: (See discussion, page 195–6).

D. C. Prince: (See discussion, this page).

H. P. St. Clair (American Gas and Electric Co., New York, N. Y.): Since R. H. Park and W. F. Skeats brought out their classic paper "Circuit Breaker Recovery Voltages" (A.I.E.E. Trans., v. 50, Mar. 1931, p. 204–38) there have been quite a few interesting demonstrations of the practical effects of this newly discovered factor in circuit breaker performance. Probably the first field demonstration in which the recovery rate theory was tested in a very practical way was described in the paper "Oil Circuit Breaker Tests—Philo 1930," by Philip Sporn and the writer (A.I.E.E. Trans., v. 50, June 1931, p. 498–505) in which a double verification was accomplished. First, calculations of recovery rate were closely checked by cathode ray oscillograms, and, second, the effect on the circuit breaker was proved when a change in the recovery rate of the circuit from 270 volts per microsecond to 2,400 volts per microsecond results in an increase in average arc length of nearly 2 to 1.

Since that time considerable further progress both in presentation of theory and in practical field and laboratory tests has been made as is shown by recent papers. In connection with the Richmond tests described in the paper by E. J. Poitras, H. P. Kuehni, and W. F. Skeats, the calculation of voltage recovery rates was complicated somewhat by the layout of the circuits involved, so that the agreement with test values was not quite as close as it has been in other cases. Nevertheless, it was close enough to indicate the order of magnitude, which after all is the important thing in voltage recovery rates. Considerable credit is due the authors of this paper for the ingenious scheme which was worked out to record the entire

voltage recovery characteristic without losing its beginning and in spreading it out so effectively on a large scale. As for the influence of these comparatively high recovery rates on the performance of the breaker under test, the results were principally negative, indicating that the arc extinguishing ability of this particular breaker was fully adequate for the recovery rates encountered.

B. E. Hagy (Philadelphia Electric Co., Philadelphia, Pa.): The authors state as conclusion 4 that the circuit breaker appears capable of performing satisfactorily under the worst recovery voltage rate condition to be encountered in the installation. It was not considered practicable to make a test that would give a calculated short-circuit current substantially equal to the breaker rating, which was very unfortunate, particularly as the short-circuit current actually obtained was not nearly so large as calculated. The measured short-circuit current under the condition of the highest rate of recovery voltage rise was about 33.3 per cent of breaker rating and under the lowest rate of rise about 40 per cent of the breaker rating.

Because it was desired to predict the values of short-circuit currents for the test reasonably closely and to establish definitely that the proposed test was sufficiently severe to yield valuable information concerning the performance of the breaker, calculations were made taking into account all the factors which it was known should be included. These calculations made it appear that a reasonable amount of short-circuit current would be interrupted. Also, calculations indicated that the recovery voltage characteristic was unusually severe, and a test under these conditions, therefore, would be more valuable from every standpoint than would be possible in the manufacturer's test plant. Analysis of the oscillograms, however, shows that the maximum current interrupted at any time during the tests was only about 60 per cent of the calculated values, or a maximum of only about 40 per cent of the breaker interrupting rating. A review of calculations showed no arithmetical errors, a large part of the discrepancy apparently being the result of generator constants being incorrect, with the remainder due to a few miscellaneous items, no one alone of which is important enough to discuss.

This situation is discussed in detail because it is desired to draw attention to the very important fact that the agreement between calculated and measured values of short-circuit current under the conditions of this test is not close enough for practical work, even when unusual efforts are made to introduce great accuracy into the calculations. It would seem that the methods of short-circuit current calculation and the data used in such calculations, particularly when the point investigated is close to the terminals of generators with cylindrical rotors, must be reviewed further.

It is probable that the development of more rational or more accurate procedure and constants for use in this work will indicate that the interrupting ratings of the more important and larger switching equipment and the mechanical design of bus structures in generating stations fixed by calculations under present practices have been on an unnecessarily conservative and expensive basis.

In connection with the recovery voltage calculations, it appears that the agreement between calculated and measured figures is good when advantage is taken of the effect of certain data from the oscillograms which apparently could not be determined with any degree of accuracy prior to the tests. The third column of table II of the paper, which is compared with the calculated values in the fourth column, includes the effect of these corrections.

It is interesting to note that under the higher recovery rates, the breaker interrupted the circuit at the earliest point at which interruption could be expected. The result is that the breaker performance apparently was unaffected by changes in the recovery voltage rate over quite a range, although this factor was important in determining the design.

Breaker Performance Studied by Cathode Ray Oscillograms

Discussion and author's closure of a paper by R. C. Van Sickle published in the February 1935 issue, pages 178–84, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935.

C. L. Fortescue: (See discussion, page 192).

D. C. Prince: (See discussion, page 193).

H. P. St. Clair (American Gas and Electric Co., New York, N. Y.): The author has made a distinct contribution toward the clarification and simplification of recovery rate theory, and has shown some very interesting cathode ray oscillograms. It is particularly interesting to see the actual application of the recovery rate procedure worked out by the subcommittee on oil circuit breaker testing of the Association of Edison Illuminating Companies in co-operation with the manufacturers, as described in this paper.

I believe we are particularly indebted to the author for the positive demonstration of the effect of voltage recovery rate on a plain-break breaker, as shown in figure 9 and in the accompanying description, in which, with all other factors approximately the same, the breaker failed to clear the arc when the recovery rate was high, but cleared successfully when the rate was lowered somewhat more than half.

In view of the increased attention being focused upon the subject of voltage recovery rate and its effects on circuit breaker performance, as evidenced by recent papers, the question may well be asked, what of the thousands of breakers already in service on every conceivable type of circuit, and presumably many of them exposed to severe recovery rate conditions? As brought out in this paper, and other oil circuit breaker tests made in 1930, one of the principal effects of a high recovery rate is increased arc length. From this it is to be expected that where high rates exist, particularly at higher voltages such as 33 kv and above, longer arc lengths resulting in increased contact burning and circuit breaker maintenance may be encountered. In a number of cases, as has been pointed out, this has actually occurred. It does not seem, however, that there is danger of actual circuit breaker failure in very many cases, as the result of a high recovery rate. Circuit breakers have been operating on many circuits where high recovery rates exist, or may exist under the right conditions, and for the most part have been fairly successful. It is true that in some cases the worst recovery rate can occur only under rather unusual system conditions, and that these conditions for a given breaker may never have occurred. One such condition would be the operation of the last breaker to clear, of a number of circuit breakers on lines connected to the high tension bus of a generating station.

As quickly as it is practicable and feasible to do so, recovery rate surveys might well be made on typical systems, and eventually on all systems. However, it is not believed that anyone should be unduly alarmed over the situation and hasten to the conclusion that many of his circuit breakers are likely to blow up at any time due to excessive and previously unknown voltage recovery rates. It is well to remember that voltage recovery rates have been in existence a long time.

W. F. Skeats (General Electric Co., Schenectady, N. Y.): In figure 2 the author shows what appears to be a failure of published formulas to match experimentally determined points. The formula which he has quoted from the Park and Skeats paper was simplified for application to the particular case of a 3 phase fault on an ungrounded system by substitution of the relation $L_1 = 2L_2$. As this relation did not hold for the present case, the curves quite naturally did not fit the points.

The correct formulas for the general case are

$$f_1 = \frac{1}{2\pi}\sqrt{\frac{(L_1+L_2)C_1+L_2C_2+\sqrt{[(L_1+L_2)C_1+L_2C_2]^2-4L_1L_2C_1C_2}}{2L_1L_2C_1C_2}}$$

and

$$f_2 = \frac{1}{2\pi}\sqrt{\frac{(L_1+L_2)C_1+L_2C_2-\sqrt{[(L_1+L_2)C_1+L_2C_2]^2-4L_1L_2C_1C_2}}{2L_1L_2C_1C_2}}$$

Curves corresponding to these formulas are shown as full lines in figure 1 of this discussion, and it will be noted that the agreement is reasonably good except for the extreme right hand section of the upper curve. The reason for the discrepancy at this point may lie in the fact that the reactance of bus and leads was assumed to be a part of the generator reactance, whereas, in this region at least, it would be considered more accurately as a part of the current limiting reactor.

The Juillard formulas referred to are obtained by simplifications of the 2 formulas given above, which are accurate if there is a

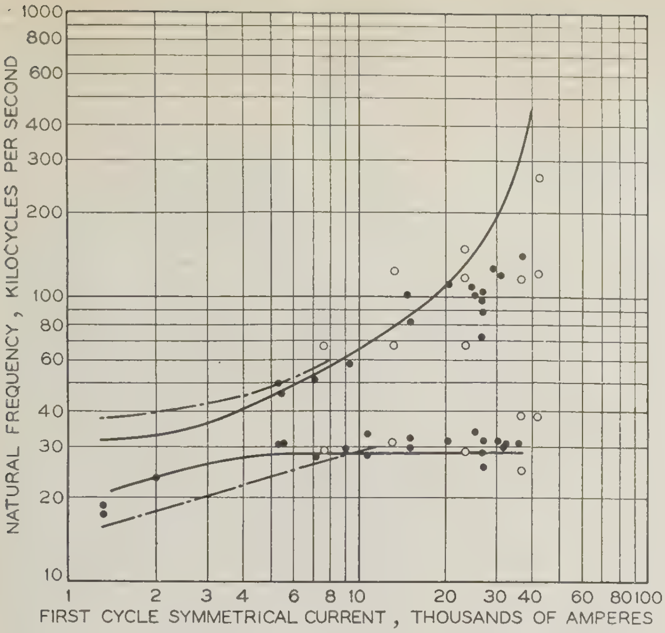


Fig. 1. Determination of the natural frequencies of a circuit

13.2-kv single-phase ungrounded circuit

Dots from cathode ray oscillograms

Circles from oscillator measurements

——— From Park and Skeats formulas

—·—· From Juillard formulas

wide divergence between the values of L_1C_1 and L_2C_2, but subject to appreciable error where these 2 values are approximately equal.

I hope operators will not be disturbed unduly by the voltage surges which Van Sickle displays in figures 4 and 6. It will be remembered that the voltage arising from the sudden interruption of a circuit at an instantaneous current i is equal to $i\sqrt{L/C}$. In most field locations, the value of C is much higher than in laboratory circuits with the result that $\sqrt{L/C}$, and therefore the resulting voltage, may be expected to be much lower.

Regarding recovery rates based on voltage peaks less than 80 per cent of the crest value of the normal frequency voltage, with some breakers these rates very probably would represent correctly the severity of the duty imposed on the breaker by the circuit; with high arc voltage, however, the high-frequency low-amplitude oscillation giving rise to these peaks may be completely damped out before the voltage curve crosses zero and starts to rise in the positive direction. In these cases, such oscillations contribute nothing to the severity of the duty. In this situation, in the calibration of testing circuits, the conservative procedure is to neglect oscillations about which there is any question, but in checking a circuit for breaker application, the reverse is the case, and all oscillations at all likely to affect the breaker operation should be included. For this reason, while the 80 per cent figure has been proposed for testing circuits, a figure of 40 per cent is recommended for application purposes.

H. P. Kuehni (General Electric Co., Schenectady, N. Y.): Only a few years back there was very little confidence in the high voltage cathode ray oscillograph. The intricate and mysterious circuits, tubes, and spark gaps were looked upon with suspicion. However, as the years went by those working with this instrument day in and day out learned to know it quite intimately, and today the cathode ray oscillograph commands respect and its rightful position in the engineering art is well established.

On account of its practically unlimited recording speed the cathode ray oscillograph is ideally suited to explore electrical phenomena of extremely short duration. It has rendered invaluable services in the study of the following:

Insulation breakdown characteristics

Insulation strength in commercial impulse testing

Effects of lightning on transmission lines and associated equipment, and the development of suitable protective equipment

Switching surges

Principles which underly circuit interruption in connection with circuit breakers, fuses, contactors, and other devices

Transient phenomena in machines, transformers, and other apparatus

The recovery voltage studies described in the recent papers by E. J. Poitras, H. P. Kuehni, and W. P. Skeats and by R. C. Van Sickle again testify to the value of this instrument. A brief description of the instrument and methods of recording may be of interest.

The heart of the cathode ray oscillograph is the fine cathode ray beam which originates at the cathode and terminates on the photographic film on which it traces its path. The cathode ray beam can be deflected by means of an electrostatic field (voltage) or a magnetic field (current). This type of oscillograph might be compared with a "time microscope" inasmuch as one may see by means of it what happened in an electrical circuit within a time interval of one microsecond. A microsecond is an incredibly short time when it is considered that a bullet fired by a high powered rifle at a speed of 3,000 feet per second requires more than 300 microseconds to travel a distance of one foot. Mechanically this is a high speed. However, electrically a mere 200,000 cycle electrical oscillation would oscillate back and forth fully 60 times while the high speed bullet is moving one foot.

In practice a cathode ray oscillogram with a time basis may be obtained in 2 ways, namely:

(a). The cathode ray beam or "electron pencil" may be made to write the record on a moving photographic film. This method is similar to that used in the well known magnetic oscillographs.

(b). The "electron pencil" may be made to write the record on a stationary film. In this case the up-and-down motion of the "electron pencil" is combined with a sideway motion similar to that in handwriting.

The original Dufour cathode ray oscillograph was equipped with a revolving film drum located in the vacuum chamber. It was driven by means of an external motor. The coupling between the film drum and the external motor was magnetic through the metal wall of the vacuum chamber. The revolving film method of recording has many attractive features and has given excellent results in the study of many problems relating to circuit interruption. As in the magnetic oscillograph, the timing is quite simple. The recording is started a short time before the test circuit interruption and is stopped after the interruption is completed. During this time the film drum may have turned around several times. However, even though the lines may have cut through each other many times the desired portion of the record can easily be picked out in most cases. Unfortunately, the speed of the film drum is mechanically limited. This tends to restrict the use of this method to cases where the rate of rise of the recovery voltage is only moderately high, as the accompanying tabulation shows. Assuming a film drum diameter of 8 inches and that it is desired to spread out the time scale of one cycle of an oscillatory wave $^1/_{16}$ inch, the following film drum and film speeds would be necessary:

Frequency of Oscillatory Wave, Cycles per Second	Time for One Cycle, Micro-seconds	Necessary Film Drum Speed, R.P.M.	Film Speed, Feet per Second
10,000	100	1,500	52
20,000	50	3,000	104
50,000	20	7,500	260
100,000	10	15,000	520
200,000	5	30,000	1,040

It is seen that prohibitive film speeds are quickly reached. Therefore, when the recovery voltage rates are high, the revolving film method of recording cannot be used.

In the early days, when the cathode ray oscillograph expert was confronted with the inadequacy of the moving film method for high speed recording, all sorts of ingenious electrical methods for obtaining a linear time axis were devised, and out of this pioneer work a high speed technique evolved. In the high speed technique of today the cathode ray beam is made to move in the direction of the time axis either by a uniformly increasing magnetic or electrostatic field while the photographic film is held stationary. The rate of change of these fields can be adjusted easily by means of predetermined electrical circuit constants of simple auxiliary timing circuits, and time constants of the order of microseconds or less are readily obtainable. Hence this method lends itself admirably to ultra high speed recording. In this, however, the proper timing of the initiation of the various circuits with the event to be recorded often becomes difficult and a great measure of resourcefulness and ingenuity is often required to solve a particular problem. It is

o know, however, that out of ...s' experience in this line of work ...ved an art which will tackle any ...m and which is willing to assure a ...a probability of success.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Realization of the fact that the rate of rise of the recovery voltage of circuit breakers is one of the important factors influencing the rupturing performance has naturally resulted in attempts to take into consideration factors relating to the rate of rise in the standardization of breakers. The author's present and also previous papers, as well as papers by other authors, are very valuable contributions toward accomplishing this, but they indicate that standardization at this time may be premature because of the practical limitations imposed by the still limited knowledge of the phenomena involved and by the available testing facilities.

This was brought home to me rather forcibly when I participated last fall in the first attempts to bring about international standardization of the rupturing capacities of breakers during the International Electrotechnical Commission meeting held in Prague. While the material contributed by Van Sickle and others in this country is limited to oil breakers of the conventional type and oil breakers with special deionizing means, it furnishes plenty of evidence of a great variety of conditions encountered during the process of rupturing. My discussions in Europe brought out the fact that an even greater variety of conditions are met with over there. As is well known there are many new types of breakers on the European market, including the conventional oil breaker, oil breakers with various deionizing means, a great many breakers using liquids other than oil, and, finally, certain air-blast breakers. It was evident not only that the rupturing phenomena of these breakers influenced in different ways the rate of rise as it actually occurred, but also that the different types of breakers were sensitive to a different degree to the various factors entering into the rupturing phenomena, such as, for instance, rate of rise of recovery voltage, maximum recovery voltage obtained, recovery value of the fundamental voltage wave, asymmetry of current, and so forth. It was noted that the performance of some of these breakers over certain ranges was little influenced by the rate of rise of the recovery voltage but very sensitive to the amplitude of the fundamental recovery wave, while with others just the reverse was true. This, of course, is to be expected.

Consider, for example, certain breakers that have slightly conducting liquids and contacts that leave the liquid during interruption. In a breaker of this kind, current can continue to flow even after deionization around the lower contact has taken place. Even though such currents are small, they may appreciably influence the entire phenomenon, perhaps even more so than the charging current discussed in this paper and illustrated in figures 9 and 10.

Because of the greater variety of conditions encountered in international standardization, both with reference to types of breakers and to system and test plant requirements to be met, it soon became apparent that any standardization with regard to the rate of rise of the recovery voltage would be futile at this time and until many more data are available. Although this was generally conceded early during the discussion, great difficulties were subsequently encountered in connection with the standardization and definition of other factors, such as rupturing current, value of fundamental recovery voltage, and so forth, on account of the greater variety of conditions to be met and the natural tendency of the various parties to emphasize those factors found to present the greatest difficulties under their particular conditions.

All of this of course indicates that there is need for carrying on intensive investigations, and also that a good deal of caution should be exercised in adopting final rules for standardization.

R. C. Van Sickle: In his discussion, W. F. Skeats has emphasized a point that was illustrated in the paper, namely, that the previously published formulas for the natural frequencies of the circuits were not general formulas and that they contained simplifications and had limitations in their applications.

The voltage surges shown in figures 4 and 6 of the paper were determined not only by the values of i, L, and C, but also by the design of the breaker. The voltage $e = i\sqrt{L/C}$ is the voltage which occurs if the arc does not restrike. In the cases shown in this paper this value of voltage was higher than the dielectric strength of the gap, and the voltage given by the formula was not reached until the end of the half cycle when it had decreased with the current, so that it no longer exceeded the dielectric strength of the gap. Increasing C reduces the voltage which can be reached and also increases the time for the dielectric strength of the gap to build up, but until the dielectric strength of the gap exceeds the voltage surge, it does not reduce the actual voltage peak.

The oscillograms, figures 4 and 6, were made on tests with breakers having ability to interrupt voltages several times the test voltage.

Circuit Breakers for Boulder Dam Line

Discussion of a paper by D. C. Prince published in the April 1935 issue, pages 366–72, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935.

Joseph Slepian (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author and his associates are to be highly congratulated on the successful development of the breaker described in this paper, and the excellent performance which it has given in high power laboratory tests. Without impugning this performance, however, I must continue to take issue with the proposed theory of operation, which seems to me to be untenable, and even incapable of accurate statement in well defined terms. Corresponding to the list of papers quoted at the end of the paper which purport to support and prove the theory, may I refer to my published discussions and that of T. E. Browne (A.I.E.E. TRANS., v. 51, 1932, p. 192–3).

The theory given by Prince makes arc extinction depend entirely on the velocity of the oil exceeding a numerical factor, dependent on the dielectric properties of the oil and the recovery voltage rise rate of the circuit, and independent of the magnitude of current, arc length, and voltage of the circuit. This last is certainly an extraordinary and bold prediction of the theory, but in complete contradiction with experimental results.

The author does not state just where in the oil the determining velocity (equation 1 of this paper) is to be observed or measured. This difficulty seems to be evaded by giving a relation between velocity and pressure (equation 2). This equation is a special case of Bernouilli's equation, well known in hydrodynamics.

Equation 2 as given, and if applicable, would give the velocity in the oil at a point where the pressure is zero, in terms of the pressure at a point where the velocity is zero. The pressure is zero, however, only at the free surface of the oil above the ports, and it is here that the velocity given by equation 2, if applicable, exists. At the contacts, and at the under side of the ports, the pressure is very much greater than zero, and, therefore, the velocity at these points should be very much less according to Bernouilli's equation, if it is applicable. But it is certainly at these points, and not at the free surface of the oil, that the significant oil velocity of the oil blast theory must occur. Hence, the supposed check which figure 3 gives of equations 1 and 2 really disproves the oil blast theory, or proves the inapplicability of equation 2 or more likely both, and indicates that the data of figure 3 are insufficient in number, and probably also poorly chosen.

However, we know that equation 2 is inapplicable on purely hydrodynamical grounds. This equation holds only for steady state motion of fluids, and only if fluid friction effects are negligible. Neither of these conditions obtain in this breaker, however. The oil is being accelerated and decelerated as shown in figure 10, where there is no proportionality whatsoever between the square of the piston velocity and piston pressure. Equation 2 is certainly not applying. We also see that there is no steady state, from the fluctuating relationship between piston pressure and tube pressure shown in figure 10. At the last current zero the piston pressure is 65 pounds per square inch while the tube pressure is 85 pounds per square inch. In figure 9, the piston pressure at interruption is 80 pounds per square inch and the tube pressure is 110 pounds per square inch. Which of these 2 pressures did the author use in figures 3 and 5, and why?

Equation 2 is inapplicable also because of fluid friction effects. The largeness of the tube pressure in comparison with the piston pressure indicates that most of the drop of pressure takes place through the ports, and with a large difference of pressure between the 2 sides of a port, the oil in the port must continually accelerate to greater and greater velocities, or else the pressure is consumed in

overcoming the frictional resistance opposing the driving of so large a volume of oil rapidly through so small an opening. The latter alternative is undoubtedly the correct one, but in either case equation 2 is not applicable.

These remarks have a direct bearing on the question of extrapolation of test results given in the appendix. If the oil blast theory of the author, which makes extinction independent of current strength and circuit voltage magnitude, is not accepted, then clearly the manner of extrapolation of test results given in the appendix is not justified.

Would the author explain a little more clearly the meaning of the statement that the oil exposed to arcing is only one per cent of that exposed in the equivalent conventional breaker? Surely he does not mean that all the oil in a circuit breaker is undergoing deterioration during the period of arcing, and actually it would seem on the contrary that a large volume of oil by acting as a diluent upon the oil actually deteriorated would be an advantage rather than a disadvantage.

It is stated in the paper that figure 10 is redrawn from figure 9, but the data in the 2 figures are widely different, so that a mistake must have been made. Could a correctly corresponding pair of figures be substituted for these in the closing discussion?

H. P. St. Clair (American Gas and Electric Co., New York, N. Y.): This paper seems to mark a rather significant step forward when voltage recovery rate can be taken into account quantitatively in the design of the circuit breaker. Whether or not the rigid relationship between recovery rate, oil velocity, and dielectric strength of oil, as set forth in this paper, can be substantiated in every case, for this particular breaker at least the performance seems to bear out the theory very well.

W. M. Leeds (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Data presented in this and previous papers indicate the effectiveness of a properly controlled oil blast for interrupting high voltage a-c arcs. The *quantitative* prediction of the interrupting performance of an oil blast breaker, however, seems to require definite knowledge of the rate of growth of an oil film at the points of interruption following a current zero. Apparently it is assumed without definite supporting data that this rate corresponds closely to the average velocity of the oil through the ports. It might be expected that the formation of an oil film would be affected both by the size of the gas bubble prior to current zero, and by the degree of streamlining of the contacts in the direction of oil motion.

Figures 3 and 5 of the paper show the limiting rate of rise of recovery voltage plotted as a function of the oil pressure. However, the proportionality between oil velocity and oil pressure, indicated by equation 2, does not appear to hold over a wide range of interrupted currents. Figure 10 shows that, during the interruption of only 800 amperes, the piston velocity dropped from a maximum of 7.8 feet per second just before the contacts parted to 5.3 feet per second at the instant of interruption. It might be expected that this effect of slowing down the piston would be even more pronounced when interrupting short circuits of several thousand amperes.

Since the full piston pressure used in interrupting high currents is also available at the light currents, will not currents of, say, 50 to 100 amperes tend to be interrupted before the natural current zero, and thus cause overvoltage surges on the system?

In figure 6 the oil level as shown is not high enough to completely fill the moulded composition insulating tube with oil. Were the high potential insulation tests made with this surface exposed to the air?

The oil blast theory indicates that the limit in voltage interrupting ability for a given oil pressure is dependent only on the rate of rise of recovery voltage, as illustrated by the separation of crosses and circles in figure 3. Can it therefore be assumed that the test breaker was operating as close to its limit at 66 kv on test No. 100 as it was on test No. 105 at 110 kv, when it failed to interrupt for several current zeros at the same rate of recovery voltage rise? Even taking into account a decrease in the surge dielectric strength of oil with increasing time of application, some other limiting factor than the rate of rise of recovery voltage may be indicated.

The discussion on extrapolation of test results brings up a number of interesting points. Since figure 4 shows that the maximum voltage which one break may be called upon to interrupt under the worst field conditions is 44 kv, it would seem that the most convincing verification of the breaker rating would be the interruption of the rated short-circuit current at 44 kv across a single break, i. e., test number 21 across one break only.

Following the line of reasoning in the appendix, if the arc interrupting function actually is not modified at heavy currents, i. e., the oil velocity remains the same, it might be concluded from the test data submitted that one break could interrupt 9,300 amperes at 110,000 volts, representing short-circuit interrupting duty to the astounding total of 11,500,000 kva on a 720,000 volt system.

Fault and Out-of-Step Protection of Lines

Discussion and authors' closure of a paper by H. D. Braley and J. L. Harvey published in the February 1935 issue, pages 189–200, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935.

J. H. Neher (Philadelphia Electric Co., Philadelphia, Pa.): The authors are to be congratulated on their clear-cut analysis and solution of what is rapidly becoming the most difficult problem with which a relay engineer must contend, that is, the relaying of a system which is or is about to go out of step. While the authors have apparently solved their particular problem by the application of existing relay types after a thorough study of the prevailing conditions, nevertheless it seems that this type of problem calls for the development of a relay which will inherently indicate that an out-of-step condition exists. Fundamentally, it would be better to arrange the fault protective system to be inoperative under surging conditions and then to break the system at the desired point by the out-of-step relay.

While several relay combinations are now in use which are designed to detect out-of-step conditions, they are open to the objection that they have difficulty in distinguishing between normal swings and an actual out-of-step condition. I believe that the development of such a relay which, as the authors suggest, would operate on the first swing which passes through an angle in excess of 180 degrees is a matter of rather urgent necessity.

W. L. Vest, Jr. (Western Massachusetts Companies, Springfield): Relay and protection engineers should be gratified to find that extensive studies to provide adequate and fast relays now greatly influence the design of important transmission lines. The Fifteen Mile Falls lines and the Boulder Dam lines are other similar recent examples. The factors of dependable fast relays and high speed oil circuit breakers, together with the necessary stability studies, determine the number and voltage of lines, and the load that may be carried safely by them. In analyzing the requirements of the protective scheme, and the reasons for selecting the carrier-current controlled type of relay protection as described in this paper, it is interesting to note the diversified factors entering into the decision, as compared with other installations of the same type of equipment.

The curves shown in figures 3 and 4 are of considerable interest. This method of plotting fault currents should be of considerable aid to others in similar problems, particularly in the study of inductive coupling between power companies and communication companies. The authors state that the data on faults from one phase to ground, shown in figure 4, were used in a study of the inductive coupling between the transmission lines and nearby communication circuits. Was this a contributing reason for deciding against the use of metallic circuits, leased from the communication companies, for the pilot channel? It would be interesting if the authors were to give further information on this subject.

In comparing the difficulties experienced in this system with the troubles on our system of relays ("A Carrier Current Relay Installation," O. A. Browne and W. L. Vest, Jr., January 1935 ELECTRICAL ENGINEERING, p. 109–15) extremely cold weather was a contributing cause of trouble in both installations. In the present case the capacitors in the line traps were affected and were changed, while on our system, the line characteristics for the successful transmission of the carrier signal shifted sufficiently so that the signals were not received at all stations. In connection with the line traps, it would be helpful to know if the small spark gaps ever have been inspected, and if any evidence of flashover was noted.

Since the paper referred to was presented, minor difficulty has occurred with some of the line coupling capacitors, which were in service about a year previous to the installation of our relays. This trouble was caused by the inner plate of the capacitor, which

consists of a sprayed coating of copper plating. With time, this coating cracked up into an infinitesimal number of small pieces of copper, each insulated from the other. A coat of conducting paint applied to the inner plate has temporarily reconnected these copper particles into a continuous metallic surface. It would be of interest to know if similar difficulty has occurred on the installation described by Braley and Harvey.

The carrier current transmitter and receiver is constructed for operation between 50 and 150 kilocycles. Was there any particular band in that range which was used, or could the frequency of any line section be arbitrarily assigned? For example, on our system, the frequency band 90–120 kilocycles gave the most desirable results.

E. H. Bancker (General Electric Company, Schenectady, N. Y.): It has been common to study the action of relays *during* faults and also the behavior of systems *after* faults. The study described in this paper extends the analysis to include the effect upon relays of the system behavior following the clearing of a fault. The complete and comprehensive study made substantiates the authors' conclusions and demonstrates the necessity for either making such studies or choosing relay systems that are not susceptible to tripping during oscillating conditions.

The wisdom of choosing carrier pilot relaying appears to be thoroughly confirmed by the results thus far attained—"no incorrect operations." Of even greater interest to those of us who had faith in the applicability of carrier current to relay practice is the careful record kept of carrier reliability. As the carrier equipment itself was the one unfamiliar and unknown factor in carrier pilot relaying, it would naturally be the object of some concern. A spirit of caution and a determination to anticipate possible troubles, coupled with the ease of testing, led to the adoption of an hourly carrier transmission test. Supplementing these are the monthly tube tests to weed out tubes before failure. The information given in table II is a complete verification of our hopes and expectations as to reliability. In the 15½ months covered there were about 90,000 hourly tests, of which only 9 failed to operate the receiver relay. Put in other words, this means the equipments were unavailable for use only one hour out of 10,000 or were capable of functioning if called upon to do so 99.99 per cent of the time. It should be recalled that the only result of a carrier failure is the unnecessary opening of a breaker for faults in the vicinity of, but external to, the line in question. A carrier failure causes nothing to trip unless undetected before the next external fault, neither does it prevent tripping for faults in the line. This amazing record of correct operation should dispel any doubts or fears of the reliability of the carrier part of the equipment.

The operating experience shows relatively few unforeseen troubles, and these were readily corrected both in the field and in the design of any future equipments. Among the conclusions the authors state that there is room for improvement in operating time. From the oscillogram in figure 9 it is apparent that there is a margin of 3.5 cycles between the time of blocking and the closing of the trip contacts. It is entirely possible to reduce this to one cycle and secure 3 cycle tripping. A still further increase in speed has been made possible by using faster directional relays that make a tripping time of 2 cycles entirely feasible for almost all short circuits. It would seem as though this should be fast enough for all practical purposes.

Giuseppe Calabrese (The New York Edison Co., Inc., New York): In regard to the out-of-step protection, the circumstances which made its use possible and its limitations should be clearly understood. For this purpose it should be recalled first that the relay used as part of the carrier current protection is a directional relay provided with a voltage restraining element. The restraining circuit is controlled by instantaneous overcurrent relays, as shown schematically in figure 8 of the paper. The relay will, therefore, close its tripping contacts when the line current is sufficiently large and within the tripping range of the relay; that is, it either leads the phase voltage, at the relay location, by not more than an angle θ', or lags it by not more than θ'' degrees, as shown in figure 1 of this discussion.

During out-of-step conditions, the angle between the internal voltages of the 2 systems varies continuously, taking all values between zero, 180, and 360 degrees. The angle between the phase voltage at any point and the line current varies also.

The performance of the relays at the 2 ends of any protected section is, therefore, dependent upon the angle θ between the 2 systems and may be calculated as a by-product of the stability study of the interconnection. However, the principles involved and the limitations of the method of out-of-step protection used perhaps may be understood better by analyzing the effect, on the performance of the relays, of their

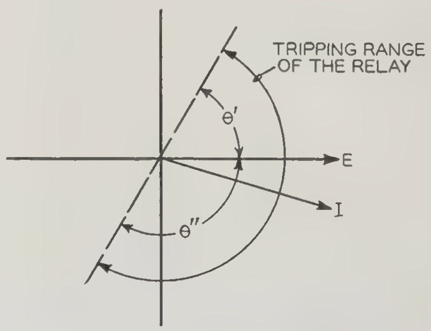


Fig. 1. Diagram illustrating tripping range of relay

E—Phase to neutral voltage at relay location
I—Line current as viewed by relay

relative location with respect to the reactance center in the simple case of 2 systems G_1 and G_2, generating voltages E_1, and E_2 of equal magnitude and tied together by means of a wholly reactive line.

Let us assume first that the 2 relays are both on the same side of the reactance center, as shown in figure 2 of this discussion. Relay *a* protects in the direction from G_1 to G_2 and its range (figure 1) extends from θ_a' leading, to θ_a'' lagging degrees ($\theta_a' + \theta_a'' =$ 180 degrees). Relay *b* protects in the direction from G_2 to G_1 and its range extends from θ_b' leading to θ_b'' lagging degrees ($\theta_b' + \theta_b''$, = 180 degrees). The values θ_a', θ_a'', θ_b' and θ_b'' are chosen usually to obtain maximum torque during short circuits.

While θ increases from zero to 180 degrees (power flowing from G_1 to G_2), relay *a* will "view" the line current in the fourth quadrant, that is, at a lagging angle θ_a, increasing from zero (when the 2 systems are in phase) to 90 degrees (when the 2 systems are 180 degrees out of phase).

Relay *b* will view the same current in the second quadrant, that is, at a leading angle of 180 − θ_b degrees, decreasing from 180 degrees (when the 2 systems are in phase) to 90 degrees (when the 2 systems are 180 degrees out of phase).

If the tripping ranges of the 2 relays are such that $\theta_a' \leqq 90$ degrees and $\theta_b' \leqq 90$ degrees, the 2 relays will never be in the tripping range simultaneously while θ

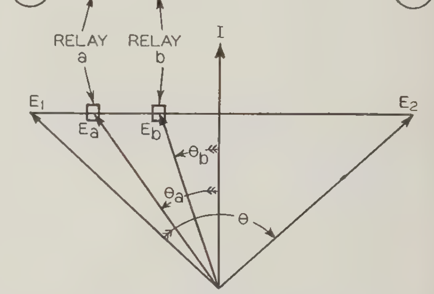


Fig. 2. Vector relations with relays on same side of reactance center

increases from zero to 180 degrees. If, however, $\theta_a' \leqq 90$ degrees and 90 degrees $< \theta_b' <$ 180 degrees, the 2 relays may both be in the tripping range simultaneously, the chances for this to happen increasing as θ_a' is decreased and θ_b' increased.

While θ increases from 180 to 360 degrees (power flowing from G_2 to G_1) θ_a and θ_b increase from 90 degrees to 180 degrees. Relay *a* will view the line current in the third quadrant, that is, at a lagging angle increasing from 90 degrees (when the 2 systems are 180 degrees out of phase) to 180 degree (when the 2 systems are again in phase). Relay *b* will view the same current in the first quadrant, that is, at a leading angle of 180 − θ_b degrees decreasing from 90 degrees (when the 2 systems are 180 degrees out of phase) to zero (when the 2 systems are again in phase). Both relays may be in the tripping range simultaneously, and the chances for this to happen increase as θ_a' is decreased and θ_b' increased.

Thus it may be seen that if the 2 relays, at the ends of the protected section, are both on the same side of the reactance center, and it is desired that they should trip during out-of-step conditions, the relay nearer to the reactance center (relay *b* of figure 2) should be given a range with as large a leading angle θ_b', and the relay further away from the reactance center (relay *a* of figure 2) a range with as small a leading angle θ_a' as possible, compatibly with correct tripping during faults and with the prevention of false trippings during swings.

The reverse is true if tripping of the sec-

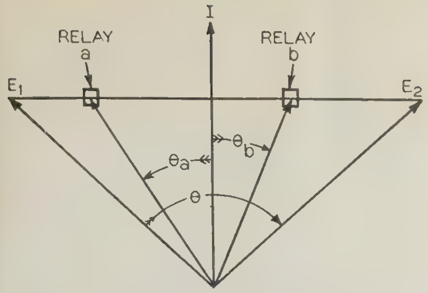


Fig. 3. Vector relations with relays on opposite sides of reactance center

tion during out-of-step conditions is to be avoided.

Consider now the case when the 2 relays are on opposite sides of the reactance center as shown in figure 3 of this discussion. Relay a will view the line current as in the case of figure 2. As to relay b, while θ increases from zero to 180 degrees, it will view the line current in the third quadrant at a lagging angle $180 - \theta_b$ degrees, decreasing from 180 degrees (when the 2 systems are in phase) to 90 degrees (when the 2 systems are 180 degrees out of phase).

While θ increases from 180 to 360 degrees, θ_b increases from 90 to 180 degrees, and thus relay b will view the line current in the fourth quadrant at a lagging angle ($180 - \theta_b$ degrees), decreasing from 90 degrees (when the 2 systems are 180 degrees out of phase) to zero (when the 2 systems are again in phase).

It may be seen easily that in this case, if it is desired that the relays should trip during out-of-step conditions, they should be given ranges with as small a leading angle as possible, that is, θ_a' and θ_b' should be as small as feasible, compatible with the prevention of false trippings during swings and with correct tripping during faults. If, however, tripping of the relays during out-of-step conditions is to be avoided, θ_a' and θ_b' should be as large as possible, compatible with correct tripping during faults.

For a more complete analysis, the variations of θ_a and θ_b with time should be taken into consideration. However, from the preceding it is apparent that the performance of the relays during out-of-step conditions depends not only on their relative location with respect to the reactance center but on their electrical distance from it as well.

The requirements as to the tripping range of relay b, when the 2 relays are on the same side of the reactance center (figure 2) are opposite to the requirements when they are one on each side of the reactance center (figure 3).

When, as the result of operating changes, both conditions are possible, the relays can be adjusted only for the prevailing condition. The New York Edison Company found that, with the exception of unusual operating conditions, the reactance center falls between Millwood and Pleasant Valley. As it was desired to clear the Pleasant Valley-Millwood section during out-of-step conditions, the angle θ' (figure 1) for the relays at Millwood and Pleasant Valley was chosen so as to make this possible, leaving at the same time, a margin of safety of 15 degrees at both stations to prevent incorrect trippings during swings. On this basis the angle θ' for the Pleasant Valley relay was made equal to 40 degrees and that for the Millwood relay was made equal to 56 degrees, as shown in figure 10 of the paper.

On the Millwood-Dunwoodie section the prevailing condition is the one with the 2 relays on the same side of the reactance center (figure 2). For reasons given in the body of the paper, tripping of this section during out-of-step conditions was to be avoided. Therefore, the angle θ' (figure 1) for the relays at the 2 ends of this section was made as large as possible (75 degrees as shown in figure 11 of the paper) compatible with correct tripping during faults.

From figure 11 of the paper and from the preceding discussion it would appear that decreasing the angle θ' for the Millwood relay would have further aided in preventing the tripping of the Dunwoodie-Millwood section during out-of-step conditions. However, this refinement was made unnecessary by the time delay in resetting, with which the relays at both Millwood and Dunwoodie were provided.

H. D. Braley and **J. L. Harvey:** The authors desire to express their appreciation of the many helpful and constructive comments on this paper. It is through such impartial discussion that the weaknesses of past developments are brought out clearly and new avenues of approach for further requirements and new developments are fostered and brought to fulfillment.

In answer to the discussion by W. L. Vest, Jr., the one-line-to-ground fault data given in figure 4 of the paper were principally for determining the relay requirements and inductive co-ordination studies, and had no bearing on the choice of the pilot channel for carrier purposes. The choice of the power line itself for the pilot channel in preference to metallic communication circuits was based principally on reliability considerations.

The line traps have not been inspected at periodic intervals although it is now planned to follow this practice in the future. The protective spark gap terminals in one trap were badly burnt, thereby increasing the effective length of gap to several times its original setting, but this did not interfere with signal transmission. This condition was discovered on an examination made subsequent to several severe lightning storms and it is assumed that the damage occurred as a result of lightning. Intermittent trouble with failure to receive carrier signals on another section of line lead to an inspection of the line traps which disclosed a defective capacitor. Thus far no difficulty has been experienced with disintegration of the metallic coating on the line coupling capacitors.

Frequency bands within the range of 100 to 130 kilocycles were found to give the most desirable results for this line.

J. H. Neher has emphasized the need for an out-of-step relay which would be generally applicable for pilot wire or carrier current control protective schemes. As pointed out in the paper, it is only by reason of a fortuitous circumstance that it was feasible in our case to adapt the line protective relays for separating the 2 systems on the preferred section during out-of-step swings. For other lines it may be necessary to employ an out-of-step relay to effect the tripping operation on the desired line section as Neher suggests. It is hoped that the manufacturers will proceed with the development work along this line.

E. H. Bancker has pointed out that higher relay operating speed could have been realized in this installation by reducing the selectivity margin of the blocking relay from 3.5 cycles to 1.0 cycle and thereby secure 3 cycle tripping instead of 5 to 6 cycles. This may be quite feasible with some of the newer equipment now available but we have felt that the number of faults actually experienced thus far have been two infrequent to justify reducing the present margin. We are in agreement with him that if equipment must be designed to give a high degree of reliability and trip in 2 cycles, it should be quite fast enough to maintain a high leve. of transient stability on practically all transmission circuits in use today.

Giuseppe Calabrese's analysis serves to simplify what might otherwise appear to present a hopeless task for the determination of the relay performance requirements. It might also be well to add that a knowledge of relay performance under such conditions is equally important if the desired operating results are to be fully realized The relay performance may be obtained by thorough tests at currents, voltages and angles known to exist on the line. The only factor affecting both the line and the relays which is not readily ascertainable is the time period of the swing. This can usually be determined with a sufficient degree of accuracy by an analysis of the stability characteristics of the line under consideration.

Surge Currents in Protective Devices

Discussion of a paper by A. M. Opsahl published in the February 1935 issue, pages 200–4, and presented for oral discussion at the protective devices session of the summer convention, Ithaca, N. Y., June 26, 1935.

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): Reliable field data on lightning currents have contributed materially to establishing the problem of protection on a correct technical and economic basis. The case of the lightning arrester is amply treated in this paper. In this connection it is well to discuss the deionizing gap, which is the protective device used in the Westinghouse "surge proof" distribution transformer. The deionizing gap is in a measure the outcome of extensive field experience with transformer installations on distribution lines highly exposed to lightning. This field experience has been closely correlated during the past 2 years with extensive laboratory investigations with lightning stroke currents. As the result of this development the deionizing gaps in this transformer can discharge practically all direct strokes near or at the transformer.

Obviously the lightning stroke current generator has played an important rôle in the development of protective devices. Lately this generator has been applied to the routine testing of deionizing gaps and thousands of commercial gaps have been tested with impulse currents of lightning stroke intensity.

Laboratory equipment has likewise kept

pace with the development of improved protective devices. The natural outcome of the lightning stroke current generator has been the combined lightning stroke current and voltage generator; the high voltage generator initiates the breakdown even of high voltage protective devices, wide gaps, etc., which the current generator alone could not break down on account of its inherently low voltage. An appropriate impedance between the protective device tested and the current generator prevents the voltage generator from discharging through the low impedance circuit of the current generator. The combined lightning stroke current and voltage generator now available permits laboratory reproduction simultaneously of both the high voltage and the heavy current of the lightning stroke, and will, no doubt, prove to be the fruitful means of further useful development.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): On page 202 of the paper a value of 12 kv per inch is given as the flashover value of wood, which is equivalent to 144 kv per foot. It is true that values of from 100 to 300 kv per foot have been used for wood, but I would like to point out that recent tests indicate that wood cannot be depended upon to give the values indicated without reference to the wood itself and its condition and treatment. Tests on some wood poles have indicated a very low insulating strength compared to that given in the paper.

The values of currents given in table I of the paper are quite representative of values to be expected for steel tower lines and are in agreement with values which have been in use for several years. It should also be remembered, however, that the majority of high voltage transmission lines are on steel with definite insulation levels.

It seems to me that the data given in table II must be used with some caution because of the wide differences in performance. For instance, one system 4,277 miles long had an average of 30 interruptions per 100 circuit miles per year, while another line, only 38 miles long with about the same flashover distance, experienced 240 flashovers per 100 circuit miles per year. However, all of the experience to date indicates that it is probably reasonable to use a rough value of 35 tripouts per 100 circuit miles per year in territory where approximately 40 storms occur per year. The actual number of insulator flashovers is greater than this as some do not cause tripouts and many multiple or successive strokes occur which are usually identified as a single flashover.

In considering the magnitude of current which reaches an arrester at the end of the line, it should be remembered that traveling waves reduce their crest value very rapidly with travel. For instance, it was shown by test ("Experimental Studies in the Propagation of Lightning Surges on Transmission Lines," O. Brune and J. R. Eaton. A.I.E.E. TRANS., v. 50, 1931, p. 1132–8) that an 860 kv negative wave was reduced to half value in traveling approximately 3 miles. At a higher potential and with increased leakage over the wood insulation the attenuation would be still greater. These factors can not be neglected when making any study of the probability of high voltages and consequently high currents reaching the lightning arrester. It is also to be noted that the attenuation with short or chopped waves is much more rapid than with long tail waves. With a chopped negative wave (see reference given) only a distance of $1^1/_2$ miles was required to reduce the 860 kv crest to half value.

I am not able to check the author's figure of 25,000 amperes to be expected based on the results obtained from reference 20 of his paper. In the reference Pittman and Torok state that the potential at the point of measurement on one conductor was approximately 5,000 kv. Using a surge impedance of 200 ohms for 3 conductors in parallel they conclude that the total current flowing in the 3 conductors was 25,000 amperes. However, the current per conductor at the measuring station, assuming all 3 traveling waves to be alike, did not exceed $^1/_3$ of 25,000 amperes. At the point struck, the current may be very high and the duty on the arrester correspondingly severe, for which, as stated by Opsahl, the arrester is not designed. Very few lines are as highly nsulated as the line investigated by Pittman and Torok, but with such lines high currents may be obtained due to direct strokes within a limited zone determined by the insulation coupled with the effects of attenuation, leakage, and discontinuities of the circuit.

With reference to the protection of distribution transformers, several factors should be included not mentioned by Opsahl, all of which have a bearing on the frequency with which lightning arresters have to carry currents of the order of magnitude discussed in the paper.

The author has suggested using 250 feet as representing a zone in which high currents would reach the arrester if a streamer or direct stroke contacted the line within that zone, and on this basis has concluded that once in 20 to 40 years a direct stroke will occur within the double section of 500 feet. For such cases, however, the arrester is not at a terminal point and the calculation shown in figure 1 does not apply. The arrester current will be reduced because of the surge impedance of the line beyond the arrester. The corresponding equation is $i_a Z_1 + 2e_a = 2E$. If arresters at terminal points only are considered, then but 250 feet should be used instead of 500 feet, which reduces the probability of high currents from once in 20 to 40 years to once in from 40 to 80 years. The probability is still further reduced through the presence of secondary conductors on the same pole with the primary. The separation between such conductors is such that potentials of the order of 500 kv to 600 kv would cause a flash between them. Such an occurrence definitely limits the current through the lightning arrester to currents of the order of those given in table I. Since every distribution transformer has secondaries, and these, in a large number of cases, are on the same pole with the primaries for a distance of the order of 250 feet or more, the reduction in probability would be considerable.

In considering the record of current measured by H. W. Collins and referred to by Opsahl, it should be stated that the measurements were in the ground connections of 3 phase arresters and not more than $^1/_3$ of 34,000 amperes can be definitely stated as having passed through one arrester.

Lightning arresters have, in general, given a very good account of themselves from the point of view of failure due to lightning surges. Laboratory impulses of high current magnitudes have been successfully passed through arresters, but until it is demonstrated that arresters can withstand the effects of the high currents of the durations which may be involved in direct strokes, and until they have demonstrated their ability to withstand the effects of the multiple stroke, they cannot be said to be safe under direct stroke conditions. Data are being accumulated which should shed considerable light on the frequency of occurrence of any particular magnitude of current both in rural and urban areas.

This paper is particularly valuable in pointing out the relative infrequency of occurrence of currents of high magnitude through lightning arresters.

Engineering Features of the Boulder Dam-Los Angeles Lines

Discussion and author's closure of a paper by E. F. Scattergood published in the May 1935 issue, pages 494–512, and presented for oral discussion at the power transmission session of the summer convention, Ithaca, N. Y., June 28, 1935.

K. B. McEachron (General Electric Co., Pittsfield, Mass.): The Boulder Dam-Los Angeles line is of particular interest to the protection engineer because of the very complete system of lightning protection which has been installed. During the past 8 to 10 years a large amount of lightning investigation work has been in progress, and this line incorporates the ideas which have come out of these investigations as to what should be done to give substantial immunity from lightning.

The extensive use of the buried counterpoise will make available operating results with reference to the use of this means of reducing tower potential. It is not likely that a more complete system will be installed in connection with any transmission line, and therefore the results will be watched with interest.

There is still some disagreement as to the proper height of ground wire for the purpose of shielding, the greater heights being advocated by those who base the calculation on the proposition that the highest object is always struck, while those who favor the less elevated ground wire base their argument on the service record of lines in existence with ground wires of the conventional height. Data are available which show that the highest object is not always struck, although such an occurrence is relatively rare. Data which would determine the efficiency of the ground wires in their present location from the point of view of shielding would, it seems to me, be of considerable value.

The over-all performance data of the line will be of greatest value if at the same time records are obtained showing the performance of the protective means as installed.

When making calculations involving the

flashover value of line insulation, proper allowance should be made for the effect of the line potential in reducing the impulse required to flash over the insulator string. This effect was first pointed out in the writer's paper, "Multiple Lightning Strokes" [ELEC. ENGG. (A.I.E.E. TRANS.) v. 53, Dec. 1934, p. 1633–7]. The maximum effect would occur when the phase conductor was maximum positive if at that instant the tower became negative as the result of a direct stroke to the tower or ground wires. The effect would be to reduce the impulse required to flashover the insulator string by approximately 7 to possibly 15 per cent, depending upon the wave shape of the impulse. The effect will be somewhat greater than the ratio of the crest 60 cycle potential to ground compared to the impulse potential, because of the differences in wave shape between the impulse and the applied 60 cycle potential.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The paper describes the principal features of this development in a clear and interesting manner, and the engineers of the bureau of power and light of the City of Los Angeles are to be congratulated for their excellent program of engineering research in connection with the transmission line and substations and the thorough way in which it was carried out. I hope that in connection with future studies of the probable lightning performance of lines in this territory there will be included a thorough survey of the soil conditions along the right of way to determine such factors as earth resistivity, probable tower footing resistance and the resistance to earth of lengths of counterpoise at different points along the right of way. I believe such a program would provide an addition of great value to the rather meager data so far available on soil conditions along transmission lines. I know of no place more admirably suited to an experimental survey of the lightning characteristics of buried counterpoises than the territory over which these lines pass. I am sure that experimental work on the towers and counterpoise system with a surge generator of suitable capacity, along similar lines to the tests made at Trafford in 1933, combined with a survey of the resistivity of the soil along the right of way of the line, could be made at little additional expense.

With regard to the design of the lines to withstand lightning, in the light of our increased knowledgd of the theory of counterpoises which has been derived in part by the experimental work at Trafford and by the record of transmission lines which have been equipped with counterpoises during the last few years, I believe that the standard of performance mentioned in this paper will be fully realized. From experience with the portion of the 220 kv line of the Pennsylvania Power and Light Company equipped with ground wires and the Safe Harbor line, I believe that the ground wires are placed a little higher than necessary, possibly 30 feet vertical separation would have been enough, but this is an error in the right direction, everything else being equal, as it does give a better shielding factor and the additional cost of the towers is probably negligible. This, of course, is hind sight, as at the time the lightning protection of these lines was under consideration it was believed with the high resistivity of soil anticipated for this project that additional midspan clearances would be required and 40 feet was not considered too conservative.

R. D. Evans (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper should prove unusually useful for reference purposes, because rarely have the electrical engineering features of a power transmission system been presented as fully and in a single paper as is the case here. This undertaking in many respects represents the most severe system stability problem which has been encountered up to the present time, and the use of high speed fault clearing constitutes the outstanding application of this method of improving system operation.

Unquestionably this paper will be reviewed in connection with subsequent projects, and for such use I wish to comment on several phases of the paper which, while applying to the present situation, appear to require qualification for general use.

The method of carrying out stability calculations as described in the paper is based on studies of conditions during 3 phase faults with corrections for the relation between 3 phase and double line-to-ground faults, the corrections being obtained by separate studies. In general, we are of the opinion that for the usual case it will be more satisfactory to compute power limits directly for the double line-to-ground fault, the condition which is accepted as the criterion for maintaining stability.

High reactance synchronous condensers at the receiving end of the transmission system are favored from the stability point of view as against the lower reactance condensers. Such a situation is rather unusual and one expects generally that lower reactance condensers will provide greater stabilizing effect.

The discussion of minimum reactance of generators appears to be slightly ambiguous. One might infer that the minimum reactance of a generator designed for 50–60 cycle operation would be less than that of a generator designed for either 50 or 60 cycle operation only. Such an interpretation is probably not intended since it does not conform with the facts.

P. M. Lincoln (Cornell University, Ithaca, N. Y.): I would like to ask 2 questions: First, what is the cost of the transmitting system from Boulder Dam to Los Angeles? The author has shown in his paper that considerations of stability will limit the capacity of this transmitting system to approximately 250,000 kw. Second, what rate of fixed charges (interest, depreciation, taxes, and insurance) does the author consider proper to apply to this first cost in order to arrive at the yearly costs for fixed charges?

I would like to submit certain deductions which I have made on the basis of assumed answers to these questions. In the matter of the first cost of the transmitting system, I am assuming $20,000,000, or approximately $70,000 per mile. I have been told that this figure is approximately correct, but have been unable to segregate this figure accurately from the data in the paper. Fifteen per cent is assumed as the proper rate for fixed charges, for if this enterprise were a private one and if I were asked as a consulting engineer to estimate the proper fixed charge rate, this is the value that I would assume. Inasmuch as the enterprise is a public one, and presumably free from taxation, the author may consider this assumed fixed charge rate as excessive. On the basis of these assumptions, one arrives immediately at a first cost for the transmission system of $80 per kilowatt, and a yearly cost of $12 per kilwatt of line capacity. Assuming further that each kilowatt of line capacity delivers 4,000 kilowatt-hours of energy per year (approximately 45 per cent load factor) at the receiving end, this is a burden of $3^1/_3$ mils per kilowatt-hour of received energy to cover the transmission cost alone, omitting all other items of fixed charge except that for transmission. In my opinion, this is too high a transmission cost to enable Boulder Dam power to compete successfully with locally generated steam power in the Southern California market.

However, if this fixed charge for transmission could be distributed over 3, 4, or 5 times the amount of energy now contemplated, the fixed charge cost of the transmitted power might be brought down to a point where it might compete with locally generated power. The only way to accomplish this is to lower the frequency of the transmitted energy. In a letter which I wrote to the editor of *Electrical World* (published in May 11, 1935, issue) I set forth the case for a lower frequency for this transmission, such as 10 cycles.

As to the objections to the use of a frequency of 10 cycles, let me point out that 3 or 4 or 5 times the power now contemplated could be carried over the transmission line by increasing the copper cross section or by raising the voltage or preferably by both methods. Such modification would mean but a small increase in line cost. To the objection that the line reactance constitutes but a small part of the total circuit reactance (a questionable statement) and consequently that the gain in line capacity before reaching the stability limit is not inversely proportional to frequency, I would point out that it is immaterial whether the reactance occurs in the line conductors or in the terminal machines. The factor which determines stability is the product of line current and total reactance—usually referred to in technical discussions as the IX drop. When the product IX reaches a certain critical value, instability occurs. In this product, X is a direct function of frequency. If X be reduced by reducing the frequency the product IX is also reduced. It does not matter whether X resides in the line or in the terminal apparatus, the product IX decreases as frequency is reduced and in direct proportion. I cannot accept the contention that it is the reactance of the line only that dictates the stability limit.

A. O. Austin (manufacturing and consulting engineer, Barberton, Ohio): The Institute is very fortunate in having the essential information upon such a large transmission system. The studies made in connection

with this line have covered many important points and have extended over a period of time probably much longer than that given to other large projects, and therefore the deductions deserve the most careful consideration. In addition to the magnitude of the undertaking there are other interesting problems in connection with this development, and it is hoped that further details and operating information will be submitted at a later time.

Some of the factors which have a bearing upon this project are quite different from those applying to most transmission systems and must be taken into account. Southern California was badly in need of an increased supply of water. This supply was made possible by the development and sale of power, which must be taken into account in comparing the cost of this power with that generated by a steam plant located on the coast.

While interconnection and the existing loads are factors which must be taken into account in the selection of a frequency, it would seem that in some of the large future projects a lower frequency would reduce the cost per kilowatt delivered. The wide range in operating conditions encountered in various sections of the line, and the care taken in the planning of the line, will furnish valuable information as a guide for future projects, and therefore it is hoped that the engineering staff will prepare papers covering the operation of the system.

It has long been apparent that high effective clearance necessary in order to provide flashover voltage in the conventional type of construction greatly increased the cost of the transmission line per kilowatt delivered. Since practically all trouble starts from phase to ground it would seem that this can be used to advantage for some of the future developments in which the conductors are placed inside the supporting masts or structures. This method makes it possible to provide a very high effective flashover voltage to ground without excessive clearance between conductors and also eliminates troubles caused by birds.

I believe a number of studies were made to determine the cost of clearance or length in the insulator string, and information on this point would be of great interest to those contemplating high voltage transmission. Information upon this point undoubtedly will show that an improvement in the "length efficiency" of the insulator string will warrant a material increase in the cost. During the last few years there has been a tendency on the part of manufacturers to concentrate upon a low first cost rather than upon improving the length efficiency which might result in an appreciable saving per structure, even though the cost of the insulators was increased materially. Information on the cost of clearance therefore is of considerable value.

Height in the structure due to ground wires or long spans tends to increase the electrical exposure, and I am glad to note that C. L. Fortescue has made the statement that the height of ground wires might be reduced to advantage. The use of high speed circuit breakers is of particular advantage as it practically eliminates the destruction resulting from power arcs, therefore it is not necessary to provide arc protection for conductor or insulators at the expense of flashover voltage.

It would seem that the engineers have given very careful consideration to all of the factors affecting the conventional type of transmission line construction, and that further improvement in the performance or cost of transmission must depend upon an improvement in some of the factors. It would seem that lower frequencies should be given very careful consideration in preference to high voltage d-c transmission. The latter offers possibilities as the potential of the conductor can remain fixed. This makes it possible to operate the conductor having the strongest electrostatic field with a negative potential, permitting much higher voltage for a given size conductor without producing radio interference or excessive corona loss. However, improvements in insulating paints or varnishes will make it possible to use much smaller conductors for a-c transmission.

While improvement in the length efficiency or corona point of the insulator will increase the cost, the total cost of the transmission line may be materially reduced particularly where the arrangement of conductors is changed so as to eliminate structures at ground potential between conductors.

Transmission lines will improve as improvements in the various elements are available. The dependence of the system for stability or the amount of power delivered upon the high speed breaker is a case in point.

The high ground resistance and the use of the counterpoise will be watched with a great deal of interest. Where the current in an arc to ground is limited there is a strong tendency to clear, and it is hoped that at some future time a line making use of this principle in preference to counterpoise and ground wire protection will be given a trial so as to determine the value of the method where the ground resistance is exceedingly high.

D. C. Prince (General Electric Co., Philadelphia, Pa.): A circuit breaker is ordinarily considered as playing a rather passive rôle. Once it has been closed in on the circuit, it stands as a guard to protect the apparatus and localize the ill effects of system faults which tend to impair service. Investment in circuit breakers and other protective gear is in the nature of insurance. Such equipment is valuable and necessary, but it does not stand out as "productive" apparatus. The investment in it is kept down to a minimum consistent with safety and satisfactory performance. Certain possible interruptions to service may even be acceptable as business risks.

Because of their beneficial effect on system stability, high speed breakers play a more active part and the super high speed breakers on the Boulder Dam-Los Angeles lines are actually "productive," because under certain fault conditions they increase the total power which can be transmitted as compared to that which could be transmitted by a slower operating breaker on the line.

In figure 2 of the paper curve *C* appears to represent the chosen features of reactance and WR^2 most nearly. With a switching time of 0.2 seconds, originally contemplated, the maximum power which could be transmitted with a fault at the sending end would be 225,000 kva. Using an 8 cycle breaker with a one cycle relay, this limit is raised to approximately 260,000 kva, or up about 16 per cent. Using 3 cycle breakers with high speed relays giving 0.06 seconds operating time, the power limit is raised 17 per cent more. The circuit breakers and relays thus take their place with the generators and transformers actually contributing to the total power that can be delivered to customers in Los Angeles.

E. F. Scattergood: Many of those discussing the paper have referred to the lightning protection system used on this line, and have expressed the desire for operating results when they become available. In planning this protection a great deal of reference has been made to the work of investigators on this subject as reported through the publications of the A.I.E.E. It is anticipated that as complete operating data as it is practicable to obtain, will be compiled and made available as it is acquired.

C. L. Fortescue has suggested that the ground wires might have been placed at a height of 30 feet rather than 40 feet above the conductors at midspan. Since the calculations by which such separations are determined involve surge impedances of the tower footing and ground wires, coupling between the conductors and the ground wires and counterpoise, together with dielectric constants of the counterpoise and also corona effects on the ground wires at lightning potentials, most of which are not too well known, it is rather difficult to determine these values precisely, or have different engineers obtain the same answer except in degree. Although the anticipated tower footing surge impedance is given as 17 to 25 ohms in the paper, it might be even lower. It is now a well accepted conclusion that the lower the surge impedance of the tower footing, the higher the lightning stroke potential can be without flashover, and the greater must be the ground wire clearance to the conductor. At the same time the greater diameter of the irregular corona envelope around the ground wire adds a considerable element of doubt as to the flashover characteristics.

A convenient reference for the purpose of this discussion is the paper "Transmission Line Design Estimates—Simplified" by A. C. Montieth (*Elec. Jl.*, v. 31, Feb. 1934, p. 72–5). The curves in figure 2*g* give values that are sufficiently close to those calculated for this line. It will be observed that if a tower footing surge impedance of 17 ohms or less is obtained, that the midspan clearance required is close to 38 feet. It is undesirable to have midspan flashovers, so some liberality should be used. The value of 40 feet is not excessive in order to achieve the desired reliability.

A. O. Austin has stated that height in the line structure due to ground wires or long spans tends to increase the lightning exposure, which is true, as the line is shielding a greater area and invites more strokes. However, reducing the height of the ground wires possibly 10 feet would decrease the exposure only about 10 per cent, but would reduce the insulation level approximately 25 per cent, which would double flashovers per year.

A point having a similar foundation is that short spans, and therefore lower towers, would have a similar effect. Roughly speaking, if the spans were reduced to 600 feet, the resulting construction to give the same number of flashovers per year, taking into account the exposure area, would require a tower approximately 70 feet high at the ground wire. A fewer number of insulator units per tower would be used (16 or 17) and a shorter crossarm would result. The final result is that more insulators are required, the stringing expense is increased, the amount of tower steel is about the same, and the footing expense is higher, leading to a higher cost for the same performance under lightning conditions. For performance as affected by dirt and fog or with regard to the likelihood of power arc follow-up, the line would be less satisfactory.

The type of construction where all of the conductors are within the supporting masts or tower structures is probably applicable where mast and guy type of construction is contemplated. However, where self-supporting structures are involved, subject to pulls of one broken conductor and one broken ground wire, as was the assumption for this line, the resulting cost of such structures is greater, as such a structure consisting of 2 lighter duty towers connected together by means of a bridge of the order of 55 feet long would be heavier than the usual single tower.

In line with the statement made by Austin about insulator length efficiency, the importance of high efficiency can be emphasized by stating that, if the string of insulators and hardware were made one foot longer, but had no higher flashover value, the extra height and width of tower required increases the weight of a suspension tower by approximately 750 pounds, for the type used on this line.

R. D. Evans is correct in stating that it is more satisfactory to compute power limits directly for the double line to ground fault, than by using the empirical correction shown in figure 2. A great many such direct calculations were made in the preliminary work. As a calculating table was not used, such considerations add considerably to the labor of calculation. The justification for the short cut is that for our particular problem, relative values could be indicated by the more simple 3 phase calculation, and that sufficient exact calculations showed such a correction to be correct for this particular setup. It is not intended to convey the idea that this same constant would work for any line one might be working with, or for every location of faults on this line.

The discussion of minimum reactance of generators that appears to be slightly ambiguous comes from the facts as presented by the manufacturers. It should be recalled that these double frequency generators were given the same rating at both speeds. Inherently, the machines have greater capacity at the high speed. A double frequency machine has the same per cent reactance on ratings proportional to speed, but if the nominal rating is taken as the same for both speeds, the per cent reactance on such a base is lower at the higher or 60 cycle speed. Incidently, the lower overspeed for this double frequency machine, resulting from the water wheel conditions, gave opportunity of obtaining higher relative inertia effects, which were also desirable.

Evans also states that it is normally to be expected that low reactance condensers would be more favorable. This position would normally be taken because low over-all reactance in a system is a very important factor in obtaining stability. With synchronous condensers, however, the reasoning is slightly different than with generators or loaded motors. Since there is no shaft torque the power angle of the machine is approximately zero, the actual reactance making only insignificant departures from this value. Higher reactance has a tendency to decrease the current output during fault, and therefore lowers the resistance load that is slowing down such a machine during the fault. During resynchronizing of the machines after the removal of the fault, the high reactance is a disadvantage. The net result is a combination of particular circumstances. For this line the difference due to reactance of condensers was very small, and happened to be more favorable for the higher reactance value.

With regard to P. M. Lincoln's inquiry regarding costs, it may be stated that the fixed charges for this publicly owned project are considerably lower than those which he has assumed, and may logically be assumed at approximately half of the value which he uses. Furthermore, the load factor will, for the major portion of the life of the project, probably be in excess of 0.7. It is anticipated that the total cost of the power in Los Angeles will be competitive with low cost steam electric generation.

The use of very low frequencies for transmission, such as suggested by Lincoln, reduces the reactance of the transmission circuits and would therefore be normally expected to materially increase the stability limit of the circuits. However, only about a third of the total over-all reactance of the complete system involved in the Boulder Dam transmission system is in the lines. The remainder is in the rotating and transforming equipment.

Our investigations have indicated that there is not much difference in the per cent reactance of any class of equipment, as it is designed for a different frequency. For example, design data for 25 and for 60 cycle generators will show that when designed to the same standards, the reactances will be only a small percentage lower for the 25 cycle machines. It will not be 25/60 of the same ohms or percentages. Similarly with transformers, it will be found that whereas the per cent reactance of a given 60 cycle transformer might be 10, the reactance of a corresponding 25 cycle transformer will be approximately 9 per cent.

It should be added that the factor that determines stability is not just IX drop, but is more particularly the relation of IX drop to the system voltage, or IX drop expressed in per cent or per unit values. If a given generator should be run at a lower frequency and at normal current, the IX drop in volts is of course proportional to frequency. However, the generated voltage is also similarly reduced, due to the lower speed, so the per cent drop remains the same. The rating has been decreased, so it would take a correspondingly larger number of machines to carry the load, and the final result is that for stability the machine reactance effects are identical in both cases.

This inefficient use of machines is obviated by designing for the particular frequency, but the proportions of parts are such that only minor reductions in the per cent reactance of this equipment is possible.

Without regard to the unusual dimensions and expense of transforming equipment for this frequency, and without regard to the feasibility of suitable designs for the proper support of the enormous field poles for the generators and motors on the 10 cycle side of the frequency changer sets, but assuming that practicable forms of equipment could be furnished, some stability calculations were made for such a system. The generator reactance was assumed slightly lower than for 60 cycles, being taken as 15 per cent. A total rating of 330,000 kva was assumed for the generators. The speed selected was 150 rpm and the inertia effect (proportional to WR^2 and square of the speed) was the same as used for the 60 cycle generators. Because of the difference in speed the WR^2 of a single 82,500 kva unit was taken as 159×10^6 pound-(feet)^2. This, if anything, is probably larger than can be built into a machine of this speed with regularly used materials. Transformers with 8 per cent reactance were used. The frequency changers were considered to have a reactance of 35 per cent, which is fairly close to the lower limit considered possible for these machines. The total rating was taken as 300,000 kva in order to deliver the emergency rating of the line. The quantity WR^2 was taken as 2,400,000 for each of 5 units running at 600 rpm. Due to low line reactance, only one intermediate switching station was used or justified.

The theoretical sending-end 3-phase fault durations that would cause instability for various loads are as follows:

Net load delivered, kw.	200,000	250,000	300,000
Duration, seconds	0.36	0.25	0.20

These permissable fault durations are approximately 0.09 seconds longer than for similar 60 cycle values.

A 10 cycle system cannot be relayed as quickly as a 60 cycle system, for certain of the phenomena pertaining to reverse power measurements are dependent on making measurements for at least $^1/_2$ cycle or longer. To avoid oscillograph-like action of mechanical parts of relays, they must be relatively sluggish. The net result is that it is not anticipated that suitable relaying can be accomplished in less than from $1^1/_4$ to $1^1/_2$ cycles. The present 3 cycle circuit breaker (60 cycle system) takes 0.05 seconds to operate. This is equivalent to $^1/_2$ cycle on the 10 cycle system. No matter how fast the circuit breaker, the arc will not go out until the first zero point after some degree of opening has been obtained. If the trip coil were energized at the peak of a current wave, it would probably take $^3/_4$ cycle to interrupt the circuit. The final result is that relaying and circuit breaker action on a 10 cycle system would take at least 2 cycles, or 0.2 seconds. This is almost exactly 0.1 second longer than is required for this action at 60 cycles, and puts the performance of the 10 cycle system at identical values to those obtained with the 60 cycle system.

It is realized that the final values obtainable in a 10 cycle system of this kind cannot be absolutely determined without an exceedingly lengthy investigation, but it can be definitely stated that from 3 to 6 times the amount of power cannot be handled over such a system.

Lincoln suggests that increasing the power limit by increasing the cross section of the conductor, and by raising the voltage, would mean only a small increase in cost. Our stability studies indicated that increasing the cross-sectional area of the conductor had an entirely negligible effect on the stability. Increasing the voltage requires increased conductor diameters, which brings higher mechanical loadings and longer insulators, both of which add materially to the conductor, tower, and insulator cost. Obviously for this project, the 275 kv line was found to be the most economical.

It is generally recognized that the use of a frequency changer to tie together portions of a system is not conducive to the greatest stability during faults, especially as the system grows. A limited investigation indicates that 10 cycle generators have impracticable dimensions that will add to the cost by making unusual construction necessary, or else requiring a greater number of units of lower rating. Also, the transformers will have dimensions and weights that would make it necessary to use a larger number of smaller rating, adding greatly to their cost. It is not believed that this system offers sufficient, if any, advantage to offset the numerous difficulties and expense that accompany its use.

A Criterion of Quality of Cable Insulation

Discussion and authors' closure of a paper by K. S. Wyatt and E. W. Spring published in the April 1935 issue, pages 417–21, and presented for oral discussion at the power transmission session of the summer convention Ithaca, N. Y., June 28, 1935.

R. L. Dodd (Milwaukee Electric Railway and Light Co., Milwaukee, Wis.): The authors of this paper have proved that by the unique and inexpensive methods they have used, the quality of the paper insulation of a power cable may be gauged layer by layer. They have also proved that the inner and outer surface contamination of the insulation is responsible for the deleterious high power factor conditions, and that cable manufacturers can prevent this contamination. It is possible then to make cable which will have low and uniform power factor throughout its entire insulation at the time it leaves the factory.

However, cable is frequently installed under conditions of internal pressures which are different from those existing when it was finally sealed at the factory. The handling and transportation of the cable may stretch the sheath somewhat and thereby lower the internal pressure. The temperature at the time and place of installation and splicing may be and frequently is lower than the temperature at the time the cable was sealed. These conditions produce a vacuum within the cable, which results in an inrush of air laden with more or less moisture as soon as the cable sheath is removed for splicing. Whatever technical tests and controls are used by the manufacturer and however perfect his product may be when it leaves the factory, this very common inrush of air as soon as the sheath is cut will permit contamination of the inner and outer portions of the insulation and defeat the purpose of the excellent precautions which have been taken up to that time.

It is suggested that to make the most use of the discoveries outlined in this paper, cables must be kept continually impregnated or must be reimpregnated before they are opened for splicing, so that pressure conditions on the inside and outside of the sheath are in equilibrium.

G. H. Arapakis (The New York Edison Co., Inc., New York, N. Y.): The authors in discussing the possible causes for radial nonuniformity of power factor and oxidation emphasize the possibilities of contamination in the manufacturing processes. This overlooks 2 other causes of oxidation which may explain, at least in part, the upturn of the curves at the conductor and lead sheath:

(a). It is known that the presence of very finely subdivided substances increases considerably the chemical reactivity of adsorbed gases, giving rise to the phenomenon known as surface catalysis. The presence therefore of fine particles of copper or lead at the conductor and sheath may partly account for the larger amounts of oxidized products at these 2 places.

(b). Oxidation is also accelerated by electrolytic action. The radical of a dielectric, which is not absolutely stable, becomes positively charged and will combine with either an oxygen or hydroxyl ion, at either the conductor or lead sheath, under the influence of a-c electrolysis. Such action would explain for service-aged cables the accumulation of oxidized products at both the conductor and lead sheath. Furthermore, copper and lead can be considered as the electrodes of a primary cell, and with lead occupying a higher place in the electrolytic potential series, oxidation will take place at the lead sheath. From the number of curves presented, it appears that power factor tends to be higher at the lead sheath than at the conductor, which may lend some support to this theory of primary electrolytic action.

It would be desirable to test the rôle played by electrolytic oxidation, if any, by placing a cable for a long period under unidirectional potential and noting any predominance of oxidized products at either the lead sheath or conductor.

In this discussion, the presence of oxygen in some form or other is assumed. The attempt is to give a possible explanation for the nonuniform distribution of the oxidized products, other than that advanced by the authors in this paper.

J. W. Bennett (Western Massachusetts Companies, Springfield, Mass.): The material contained in this paper represents a valuable addition to the published data on paper insulated cable. It also shows the desirability of checking academic theories by experiment wherever possible.

It is quite evident from the results of tests as given in figures 2, 4, and 5 of the paper that the quality and uniformity of their product can be improved by the manufacturers if a suitable method of detecting its shortcomings is available. This is particularly evident from a comparison of the curves in figures 4 and 5.

Most of the tests discussed in this paper were made on 3-conductor 24-kv cable. I should like to ask the authors whether or not they have made any tests on single conductor cable of comparable voltage, and if so how the results of these tests compare with those on 3 conductor cable.

There seems to be little doubt that the quality of paper cable can be raised to a high value by carefully controlled and efficient methods of manufacture. This improvement in quality and uniformity of cable will, undoubtedly, help to increase its operating life.

While improved quality of the manufactured product is of paramount importance in any attempt to increase the useful operating life of power cables, the other factors affecting this problem must not be overlooked. From test and experience it is known that the quality of solid type paper insulation can, and frequently does, deteriorate in the storage yard. Unless care is taken in the installation, it is possible for foreign matter, such as dirt or moisture, to enter the cable at that time, with a consequent acceleration of insulation deterioration.

A certain amount of contamination at, or adjacent to, the cable joint, is almost inevitable even under the most carefully supervised conditions of installation. Some aging of insulation in storage may also be expected. These 2 facts suggest that it might be desirable to consider the partial evacuation and impregnation of cable at the time of installation.

Research of the type described in this paper is of value to both manufacturer and operator, and I hope that the authors will continue to publish the results of their work in this field.

W. A. Del Mar (Habirshaw Cable and Wire Corp., Yonkers, N. Y.): The authors are to be congratulated on their development of a new instrument for the study of dielectrics, and there is no doubt but that this instrument will prove of great value both in diagnosing cable trouble and furnishing information which will lead to new developments in dielectrics.

There is, however, an unfortunate lack of accuracy in many statements in the paper, such as in the frequent references to "radial uniformity" as a criterion of quality. Probably the authors meant to say "lack of accidental or erratic variation in the radial power factor," which is a very different thing. No evidence is offered to show that radial uniformity in power factor is a desirable characteristic. On the contrary, I believe that the various systems of grading, with which manufacturers are now experimenting, are sure to lead to radial non-uniformity.

Is it not possible that a high power factor of the inner tapes may be a good thing? Cable deterioration starts in the oil at the conductor surface and if the oil can be kept hot and expanded as the remainder of the cable cools, will not ionization be reduced or retarded? There is a lack of evidence that even erratic radial variation of power factor is harmful, although the presumption would be in favor of this idea.

The points I wish to bring out are that

something is being taken for granted without any kind of evidence, and that there are certain essential characteristics which affect the behavior of a cable in service which we are likely to lose sight of while chasing a new will-o'-the-wisp. For example, the first tape or so nearest the conductor is usually of abnormally high power factor because of the wrinkling it receives by pressure against the strands. This can be avoided by applying the tapes loosely. Therefore, if the Wyatt-Spring criterion of quality is to govern, tapes will be applied loosely, to the great deteriment of cable quality.

The use of superdense paper near the conductor has the effect of increasing stress on the oil, hastening oil deterioration at the conductor in the course of a voltage-time test, as shown by radial tests. Nevertheless the cable performs better at normal voltage with a certain amount of this paper, showing that the radial tests may be quite misleading.

Other inaccuracies are in the comparison of cables *A* to *D*, the radial curves of which are shown in figure 2. Thus it is stated that the use of rosin masks small variations in manufacture. The curves indicate the contrary, as the only one with small variations is curve *C*, which represents a rosin-bearing cable. At the time when the cables for these tests were collected, cables without rosin were all made with carbon dioxide washing, while those with rosin were not so treated. Is it not probable that the uniformity of the *A* and *B* cables is due more to carbon dioxide washing than to absence of rosin? Washing with carbon dioxide certainly tends to produce uniformity.

The details of the method of test are not very fully covered by the authors, as indicated by the following uncertainties:

(a). It is not stated whether the tapes have been wiped to remove free oil, or left oily as stripped from the cable. There is a considerable difference between power factors in the 2 cases, the unwiped tapes showing from 10 to 50 per cent higher power factor. The dielectric stress in the oil being some 70 per cent greater in the free oil than in the tapes, there is a tendency for residual moisture to concentrate in the free oil, which may explain this difference.

(b). More accurate measurements are obtainable at 1,000 cycles than at 60 cycles, the increased power factor of the inner papers is more pronounced, and the beginning of the belt, in belted cable, is more clearly indicated. Nevertheless, the 60 cycle readings are more erratic than the 1,000 cycle readings, indicating that erratic results may be introduced by the method of test.

(c). The distance from the end of a sample which is required to obtain a representative sample is open to doubt. An end left open to the air for a few hours is likely to show erratic radial curves, for a considerable distance, even though the cable in general is very uniform radially.

(d). The electrode pressure has quite an influence on the power factor of an aged cable because it determines the amount of surface oil which remains on an unwiped sample.

(e). The temperature of the paper tape is somewhat open to doubt in spite of the ingenious construction of the instrument, as the thermometer is necessarily located at some distance from the tape. Tests on different instruments are not always consistent.

H. H. Race (General Electric Co., Schenectady, N. Y.): This paper is one of a series describing methods for studying physical properties of cable insulation as functions of radial distance from the copper core. The authors have studied power factor of the oil filled tapes and also hydrophil content of oil extracted from such tapes.

As an extension of this type of minute examination of portions of oil impregnated paper insulation, a guarded cell for measuring the dielectric constant and power factor of a drop of oil has been made. Measurements to 5 per cent accuracy can be made on 0.1 gram of oil, which amount can usually be extracted by centrifuging a few square inches of paper tape removed from any portion of cable. Thus the electrical properties of oil in individual paper tapes can be studied for correlation with microchemical tests on the oil alone and other physical tests on the oil impregnated paper.

The construction of this small oil cell is unique, having been made possible by the development of a special metal alloy called "fernico" having the same temperature coefficient of expansion as certain commercial glasses. The cell consists of 2 circular plane parallel plates mounted so that they can be set from 0.01 to 0.02 centimeter apart. One plate is solid metal, the other is made by sealing a cylinder of glass about 0.05 centimeter thick between the measuring electrode, which is a disk 1 centimeter in diameter, and an outer guard ring about 0.2 centimeter in width. The surface of the completed disk is ground flat, leaving a surface which can be easily cleaned, and having a guard ring permanently mounted on but insulated from the measuring electrode. Figure 1 of this discussion shows this electrode with the brass yoke showing through the glass between the measuring electrode and the guard ring.

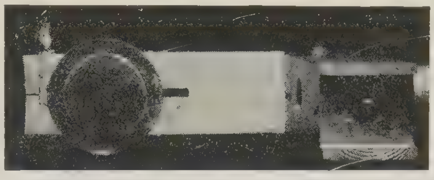


Fig. 1. Measuring electrode of small cell for measuring dielectric constant and power factor of 0.1 gram of oil

Shown approximately actual size

G. B. Shanklin (General Electric Co., Schenectady, N. Y.): Since these authors first described their radial power factor method of testing cable, like other cable engineers I have watched this new industrial tool closely and have attempted to evaluate and catalog it on the basis of existing evidence. The conclusions I intend to present can be regarded as only tentative, for this method is still too new and experience with it too limited for final evaluation and co-ordination with established knowledge of cable characteristics obtained by other means. Nevertheless, I believe these conclusions are reasonably near the truth and will be confirmed as further experience is gained.

There is no question about the value of this test method as a contribution to the cable art. I am glad, however, that the authors designate it as *a* criterion quality rather than as *the* criterion. The only real criterion of cable quality is durable service life. As a single test criterion, the nearest approach to this is the load cycle overvoltage endurance run, as developed and used in this country and abroad. This test, however, is expensive, complicated, and long drawn out. Auxiliary tools are necessary and helpful. In this respect the radial power factor test is valuable, but I would again emphasize that no single test nor single cable characteristic is a final criterion of service life.

The radial power factor test is definitely associated with the old established dielectric loss test on finished lengths of cable, the only difference being that instead of measuring the mean average power factor of a finished length, small areas of the component paper tapes are measured and the results plotted in the form of a radial curve.

The first conclusion is that the old reliable method of measuring the dielectric loss of finished lengths will not be displaced. The radial method is mainly supplementary. This leads to the further conclusion that cable stability, as represented by change in power factor, is best determined by periodic measurement on finished lengths. In other words, if the average mean power factor does not change noticeably, then the radial power factor curve has no real significance.

The second conclusion is that the U shape of the radial power factor curve is normal and inherent in all paper insulated cable, and is the result of localized oxidation action in the impregnating oil, accelerated and increased at the conductor and sheath zones by the catalyzing effect of the metals in near proximity. The shape or steepness of this U curve indicates the amount of oxidation products present. In a well made cable reasonably free from impurities the curve, while the cable is new, should be rather flat and shallow with an up bend at each boundary extending through only a few layers of paper. After a period of service, however, the steepness of the curve will normally increase as the oxidation action proceeds.

This will continue until the oxidation action is completed. If, at this time, the average effective power factor of the cable as a whole has not appreciably increased, then the radial curve neither in shape nor degree has any real significance nor does it give any true indication of cable life.

If a cable contains more than normal traces of oxidation impurities, the steepness of the U curve is more pronounced and there is a corresponding increase in average effective power factor. This may or may not continue to the point of affecting cable life, depending upon the amount of impurities present and other factors.

From the foregoing one might ask why it is not desirable to go the whole way, eliminate all traces of oxidation impurities from the cable, and obtain an absolutely flat radial curve from conductor to sheath. The answer to this was discovered long before the radial method of test was known. It has been proved to be a dangerous thing to do. The cable would be too pure to live long.

The only way an absolutely flat radial curve could be obtained would be to use such highly refined materials and methods of manufacture that not even traces of hydrophils remained in the finished product.

This has been tried and the finished cable, while having remarkably low power factor and stability as far as oxidation is concerned, had no ionization stability or voltage life at all. Under such conditions voids and ionization seem to form easily with cumulative generation of hydrogen gas and formation of "*X*" wax. Experienced chemists and physicists claim that without a certain amount of such oxidation products the oil loses its "wetting ability" and will not cling to the paper fibers or form a tough film between tapes. This explains, at least in part, why some cable engineers still prefer a little rosin in their compounds.

To summarize these conclusions it might be stated that the radial power factor test is a valuable contribution to the cable art, always provided its results are rightfully interpreted. I hope sincerely that the cable users will not become too alarmed when they discover U curves in their cable and insist too strongly that cable be furnished with perfectly and permanently flat radial curves. After all, cable now being furnished has a rather perfect operating record as far as insulation quality is concerned.

D. W. Roper (Commonwealth Edison Co., Chicago, Ill.): Radial power factor tests as described in this paper have been made in connection with accelerated aging tests of 66 kv cable now in progress in Chicago. Figure 2 of this discussion shows the curves for 10 cables before being subjected to the aging tests. In order to determine the influence of the radial power factor on the life of the insulation, samples covering the entire range of quality which occurs in such cable used in Chicago were purposely included. Some of the samples of the poorest quality were new cable made several years ago and others had been in service, during which they had deteriorated.

The aging tests consisted of the simultaneous application of overvoltage and daily load cycles resulting in a maximum temperature of about 65 degrees centigrade at the conductor. The first 5 cycles were at $2^1/_2$ times normal voltage during which 4 cables failed. Trouble with the joints necessitated reduction to $2^1/_4$ times normal for the next 17 cycles during which no cables failed. It was apparent that the standard joint design, which was entirely satisfactory in service, was not suitable for these tests. The design was modified and the next 9 cycles were at $2^1/_2$ times normal during which 6 cables failed.

This trouble with the joints is mentioned here for the benefit of other investigators who may make aging tests with joints in the set-up. Apparently, the joints for such tests must have at least 50 per cent longer leakage path between the factory applied and hand applied insulation, and have slightly more insulation radially than joints used in normal service. Also, it is important that the hand applied tape have relatively low power factor at the temperatures attained in the tests.

The order in which these cables failed in the aging tests shows a very good agreement with the initial radial power factor data. Cables 1, 2, 3, and 4 were obviously inferior in the radial power factor characteristics and their early failures were predicted. Cable 7, which was very nonuniform along the length, was expected to fail before cable 5, but is obviously of about the same intermediate quality. Cables 6, 9, and 10 are next in general order of excellence in quality and for these cables as well as for the best one as indicated by the radial power factor data, that is, cable 8, other factors in the cable samples predominated to cause slight variations in the order of failure from the predicted order.

These data indicate that cables of poor quality can be properly judged by the initial tests without making the far more costly and lengthy aging tests. This is one important use of the radial power factor tests. Since the aging tests of the cables of better quality are still in progress, the extent to which this application is suitable has not been determined.

Figure 3 of this discussion shows radial power factor curves measured before and after the aging tests on the fifth cable to fail. Both the U shaped power factor curve and the early failure indicate poor quality. Closer examination of the data indicates the following:

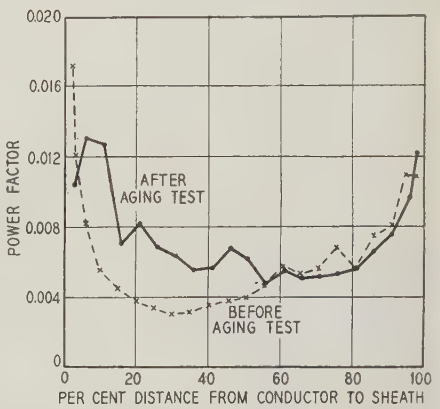


Fig. 3. Curves showing radial power factor of a 66 kv cable at 60 degrees centigrade

(a). The materials used in this cable were about as good in quality as the best now obtainable. This is indicated by the minimum power factor of 0.3 per cent at 60 degree centigrade, which is nearly as low as the lowest now obtainable.

(b). The insulation was not thoroughly impregnated. This is indicated during aging by the increase in power factor in the inner half of the insulation where the compound had changed to wax.

(c). Contamination occurred during manufacture by entrance of oxygen or dirt both from the outside and inside of the insulation wall. This is indicated by the upturns in power factor toward the conductor and sheath which involve practically the entire thickness of insulation.

These conclusions concerning the significance of the data as applied to the manufacture of the cable were verified by the manufacturer of the cable.

Figure 4 of this discussion shows the radial power factor curves for a 60 kv cable of foreign manufacture, designated by the letter *A*, and 4 makes of 66 kv cable made in this country. The radial power factor tests show that the foreign cable is not so good in quality as 4 domestic cables of recent manufacture. The 60 kv cable of foreign manufacture has 550 mils of insulation, while the 66 kv cables of domestic manufacture have 688 mils of insulation. The 60 kv cable operates satisfactorily with 14 per cent higher stresses than the 66 kv cables and with a poorer grade of insulation. These data indicate that the thickness of insulation for the 66 kv cable could be

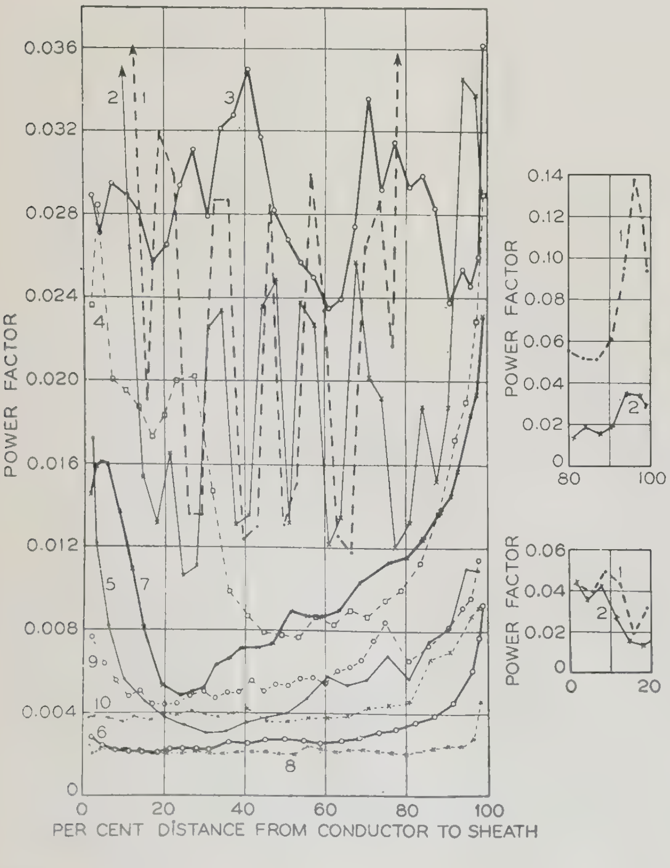


Fig. 2. Curves of radial power factors of new and used 66 kv cables at 60 degrees centigrade

Numbers indicate order of failure in aging test

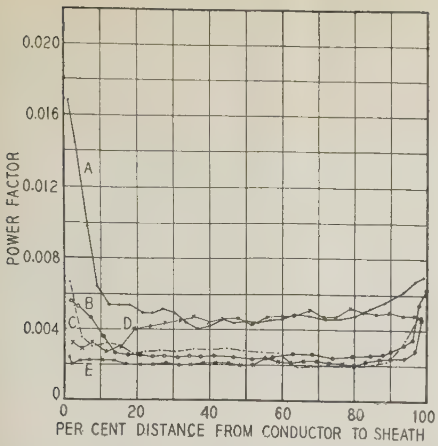


Fig. 4. Curves of radial power factor of high-voltage single-conductor cable at 60 degrees centigrade

A—60 kv cable of foreign manufacture
B, C, D, E—66 kv cable of American manufacture

reduced safely by from 10 to 15 per cent.

These tests indicate that the radial power factor tests will be found useful not only by the manufacturer in determining the manner in which the insulation can be improved, but also by the purchaser for comparing the quality of cables submitted.

R. W. Atkinson (General Cable Corp., Perth Amboy, N. J.): Throughout the history of the use of dielectrics, much of the improvement in the material and its use has needed to await the development of "tools" and methods of using them. An important part of the work of those interested in the development of the dielectric has lain in the development of the tools. The tape tester developed by the authors is a typical case in point, and these authors deserve credit for recognizing the need of a satisfactory means of measuring radial variation in power factor in cable and for developing the apparatus and technique for this purpose. When this tape tester was first announced, the company which I represent had one made from specifications kindly furnished to it, and we have found this piece of apparatus to be all that we hoped it to be.

I would like also to say a word for the apparatus more recently developed for this purpose by A. L. Brownlee of the Commonwealth Edison Company. Similar measurements are made with this, but with the advantage that an extremely small sample of tape is used which adds greatly to the adaptability of the apparatus for some purposes. I believe that similar details of his apparatus are available.

Marked improvement in the dielectric properties of cables has come about already as a result of the development of the tape tester and of the information furnished by these authors showing the wide radial variation of power factor in earlier cables. This apparatus has taken its place as a valuable tool in the manufacture of cable as well as in the study of properties of completed cables. I would add the warning, however, that there always is a tendency in the case of new apparatus to overemphasize the importance of measurements made with it. Important as are the determinations made of power factor of individual tapes of a cable, overemphasis on this must not be permitted to divert attention and energy that should be given to other matters which are essential in a balanced program.

That the importance of this is limited is illustrated by D. W. Roper in his remarks about a cable of foreign manufacture, concerning which he has given data. His curve very well illustrates the improvements which have come to American cable as a result of the availability of the radial testing, by comparison with the poorer values found in the foreign cable. However, he left no doubt that he felt this example of European cable to be representative of the best European practice and that further he felt no qualifications regarding its high quality. He did not indicate that he felt the radial nonuniformity affected its being very good cable.

A word should be said about comparison of insulation thicknesses of European and American cables. Aside from the differences in operating conditions which are favorable to European cables and have frequently been discussed, it should be observed that European practice is to base the nominal or rated thickness of insulation upon the *minimum* thickness, whereas American practice is to base the rated thickness upon the *average* thickness. Thus, the actual European thicknesses are 5 per cent or 10 per cent greater for the same rated thicknesses than are the American, which fact should be taken into account when comparing rated thicknesses of European cables with those of American manufacture.

C. G. Brazier and **D. M. Robinson** (nonmembers; Callender's Cable and Construction Co., Ltd., London, England): We are in agreement with the authors' observations of fact, namely that there is a U shaped curve of power factor throughout the dielectric wall, and a corresponding curve of hydrophil content. However, we find ourselves definitely unable to join with the authors in their explanation that "the hydrophil curves represent oxidation of the insulation."

Taking from the paper an average rise of hydrophil content of 0.2 per cent, it can be calculated, taking the most conservative assumptions at all points, that an absolute minimum of 37.5 cubic centimeters of air would be required per 100 grams of cable compound. For 100 yards of cable of about 2 inches diameter, this corresponds with a requirement of 30 liters of air to supply the necessary oxygen. We find it impossible to believe either that this amount of air is breathed into the cable through a porous lead sheath, or that this amount of air is left in the cable at the moment of impregnation, since in this case it would be impossible to obtain the ionization figures which are given for our present cables. The figure of 30 liters, in fact, can be compared with the calculated volume of residual air in the cable at the moment of impregnation, when the impregnation vacuum is brought down to a figure of 0.1 millimeters of mercury, which is 0.035 liters per 100 yards of cable, or approximately $^{1}/_{1000}$ of that required by the authors' theory.

Moreover, we note that in a recent paper by D. W. Roper "Notes on Practical Application of Insulation Research" [report of committee on electrical insulation, National Research Council, Washington, D. C., 1934; see also Elec. Engg. (A. I. E. E. Trans.) v. 54, Aug. 1935, p. 816–21] a similar kind of discontinuity in the hydrophil and power factor curves is found at the junction in the dielectric wall between 2 different types of paper or papering. It appears quite impossible to explain an effect of this kind by the authors' oxidation theory.

Therefore it may be concluded that the power factor and hydrophil content does vary in the manner described in the paper, but that this is not the result of oxidation of the compound.

J. B. Whitehead (The Johns Hopkins University, Baltimore, Md.): The authors emphasize particularly the value of their method of examining the radial variation of the electrical properties of impregnated paper for improving the quality of manufactured cables. Certainly such results as those presented in figures 2, 4, and 5 of the paper should convince anyone that the authors are warranted in their modest thesis.

The authors might have gone much further in emphasizing the value of their method for general research purposes. Thus they apparently attribute the high values of power factor at conductor and sheath entirely to oxidation of the saturant. This is undoubtedly one of the most serious causes of the deterioration of oils and therefore, in all probability, the first such cause to be uncovered by these methods. It is also in all probability the one that is most easily combated as indicated by the methods adopted for improving the 1933 cable of figure 2.

However, the evidence is not clear that all of the trouble is due to oxidation. For example, in figure 4 the increase in power factor at the sheath is proportionately very much greater than the increase in the hydrophils. It is to be remembered that gaseous ionization probably occurs most often near the sheath and that a very brief period of such ionization may cause other forms of deterioration. Moreover, the causes cited by the authors for the oxidation in the neighborhood of the sheath certainly do not apply equally strongly to the layers nearest to the conductor. Yet in many cases the increase in power factor in the latter region is just as great as near the sheath.

In recent research on insulating oils increasing attention is being drawn to the conditions which obtain at the layer of contact between oil and metal. In the purest oils residual conductivity and loss is being attributed less and less frequently to residual impurities, and more frequently to the presence of electric stress, to possible radioactive influence, or to cosmic influence, both as affected by conditions at the surface layer between metal and dielectric. The question involves not merely the chemical relationships of the materials involved, but also the physical conditions such as microscopic surface irregularities, temperature, and perhaps other factors.

Furthermore, the method would appear

to offer fine opportunity for the study of progressive deterioration. New evidence has recently been presented of the influence of electric stress alone as a deteriorating agent. The picture is that the oscillation of free ions present in an oil either by collision, or friction, or otherwise, necessarily tends to upset molecular equilibrium. The free ion content of the whole range of oils considered to be good and as used in cable insulation varies in the ratio of 1 to 1,000 or more. The industry now uses no method for determining the free ion content of the oil. Yet it is certain that the rate of deterioration increases with the free ion content.

Another question closely related to the foregoing is the point at which deterioration of impregnated cable insulation is most rapid. It would appear almost certain that of the various radial distribution curves shown by the authors, deterioration would be most rapid at either sheath or conductor. On the contrary, in carefully controlled laboratory samples, not only are over-all power factors substantially lower than those shown in figure 2, but in many accelerated aging tests, the most rapid deterioration and the beginnings of failure have been found to occur near the center of the insulation wall.

Among others, this method would seem to offer great promise in studies of the following questions: the relative catalytic activities of various metals as related to various oils, and as affected by residual moisture and residual gases of various types; the changes in the original values, as related to these various factors, which result from the continued application of high electric stress; the relation of the original free ion content of the oil to these subsequent changes; and more careful studies of progressive variation of radial distribution of power factor in carefully controlled accelerated aging tests.

K. S. Wyatt and **E. W. Spring:** From the discussion it is evident that the apparatus and method described earlier (reference 1 of the paper) have found application in both utilities' and manufacturers' laboratories. Their rapid adoption appears to indicate that the manufacturers are ever alert to take advantage of new tools which may help to improve their product, and this is indeed a healthy sign for the industry.

We join with R. W. Atkinson in commending A. L. Brownlee's apparatus which because of the small area of tape which is measured, makes it possible to go farther than our apparatus and to measure the variation in power factor around each turn of paper tape, or to explore the deterioration in the vicinity of failures.

Replying to J. W. Bennett, we have not employed the radial method on single conductor cable in the same voltage class as the 3-conductor 24-kv cable on which most of our work was done. We have made a few measurements on single-conductor 66-kv cable from service which led us to believe that the deterioration as indicated by the radial power factor curve was not so serious as in 3-conductor 24-kv cable; this we thought might be due to lack of filler spaces in single conductor cable which serve to some extent as channels along which air and moisture may travel when a cable end is exposed, as for example in jointing in cold weather. A great deal of work with radial power factor measurements has been reported on single-conductor 66-kv cable by D. W. Roper ["Practical Applications of Insulation Research," Elec. Engg. (A.I.E.E. Trans.) v. 54, Aug. 1935, p. 816–21], although, of course, no comparison could be made with 3 conductor cable. In cases where marked deterioration occurs because of the filler spaces in 3 conductor cable, the reimpregnation method suggested by R. L. Dodd should prove useful.

The points raised by G. H. Arapakis are of great interest. There can be no doubt that the presence in cable of such active oxidation catalysts as copper and lead affect the rate of deterioration in the vicinity of the conductor and sheath. It has recently been reported that oil taken from operating cable contains copper in finely subdivided or colloidal form, in which state the metal is far more active due to the large surface area; the catalytic effect of such copper obviously would increase still further the oxidation rate. The final effect of the oxidation catalysts, such as copper, lead, and paper lignins which are present in modern cable, is discounted by many on the ground that, since an operating cable is a closed system and the amount of oxygen available for combination with the oil is limited, catalysts can only increase the rate of oxidation but cannot change the final amount of oxidation. The quantity of oxygen entrapped in the cable is small, so that all that catalysts could do would be to effect an oxidation in a few months which in their absence would take place within a year or so of operation and certainly long before the cable reached the end of its useful life, i. e., 20 years or more. This argument leads us to look for the source of the oxygen in new cable; it may be dissolved in the oil, mechanically entrapped in small void spaces between the layers of paper, or in the paper cells from which it has not been displaced by the oil impregnation process; it may be adsorbed on the paper fiber or metal surfaces; it may be in combined form as in lignins, resins, or other impurities which are present in most kraft papers in quantities from 1 to 3 per cent; or finally it may be the more stably combined oxygen of the cellulose, of moisture in the paper, or even of the 0.3 per cent cuprous oxide in the copper conductor. With oil filled cables, of course, oxygen may be introduced by way of the reservoir oil fed into the core. Quantitative evaluation of each of these sources of oxygen leads us into another difficulty: if we measure the amount of oxidation products in the oil of some badly deteriorated cables, the corresponding amount of oxygen is so great that it could not have been all dissolved oxygen, and it is difficult to believe that such a volume could have been inbreathed. So far we have not arrived at a satisfactory explanation. (See also discussion by K. S. Wyatt, A.I.E.E. Trans., v. 52, Dec. 1933, p. 1025–7.)

This brings us to Arapakis' second point: is it not possible that some of the combined oxygen may not have been liberated by electrical stress, as for example, electrolysis of moisture? This mechanism was considered in our earlier paper, but it could not explain many cases of deterioration. For example, in belted cable we found the radial power factor curves resemble 2 U's in shape, one U for the core insulation and one for the belt. The upturn at the junction between core and belt was in many cases just as pronounced as at the conductor, even though there was no metal present to act as an electrode. These cases do not rule out electrolysis as a possible source of oxygen, but they show that it is not one of the important sources in 3-conductor 24-kv cable such as we operate.

The quantitative aspects of oxidation theory have been questioned by C. G. Brazier and D. M. Robinson. As we pointed out in replying to Arapakis, it is impossible at the present time to account other than qualitatively for the hydrophils present in many deteriorated cables. It is possible that the sulfur compounds in the oil contribute slightly to the hydrophil content. The paper impurities are another possible source of hydrophil spread. Arapakis has suggested electrolysis of moisture. Qualitatively we have found that the major part of the deterioration such as we observe in 3-conductor 24-kv cable is due to oxidation. Of course, as has been pointed out, air dissolved in the cable or inbreathed during operation may not be the only source of oxygen. With regard to the discontinuity in radial power factor curves observed in the paper by Roper (already referred to) at the junction between 2 types of paper in cable in which the insulation was graded, we think this is to be expected because the porosity and the purity of the 2 papers would be entirely different. Moreover, at such junctions there is a small but sharp change in specific inductive capacity, which may result in a steep local potential gradient which may cause gaseous ionization; in fact, we have observed in cables which have been subjected to load cycle tests with continuous overvoltage that small amounts of wax are sometimes formed at such a junction. We do not recall discontinuities of the radial hydrophil curve in such cases, but since bombardment in vacuum of oxidized cable oil results in polymerization and condensation of the oxidation products and thus a marked reduction in oxidation products as measured by the hydrophil method, we should expect a discontinuity in the radial hydrophil curve. As we pointed out in our earlier paper, there is no agreement between hydrophil and power factor where gaseous discharge as evidenced by wax has taken place. The quantitative explanation of the deterioration phenomena in cables must wait upon more experimental work, and we consider it fortunate that attention has been drawn to this angle of the problem. We do not think that any possible mechanism such as electrolysis should be entirely discarded even though our limited observations so far cause us to reject it. Electrolysis of moisture in cables, for instance, would be a most important finding, and we trust others who have a wider choice of service aged cable to work on will weigh carefully all possibilities.

We are particularly pleased at Shanklin's remark that our test method has proved of service since it was from his associate, G. M. J. MacKaye, that we first received encouragement to continue the search for an explanation of the U-shaped hydrophil curves, and later in connection with radial

power factor from Shanklin himself. The view that the best criterion of cable quality is life in service and that the nearest approach to an accelerated test for it is the load cycle aging test is one with which we are in full agreement. We feel, however, that it may be possible to develop simpler, less complicated tests which will reveal the basic characteristics of oil impregnated paper upon which life in service chiefly depends, thus enabling us, except in occasional checks, to avoid the expensive load cycle tests. More micro-tests, in distinction to over-all tests, are needed to measure the variation in properties of insulation from point to point. The radial tests for power factor and hydrophil layer by layer from sheath to conductor which we have described are just such tests, and we hope they will be the forerunner of many other such tests, giving new information which the over-all test cannot give. There is a great deal of new information waiting to be obtained by those who develop new micro-tools such as the ingenious cell for measuring power factor of droplets of oil which H. H. Race has described. Another point Shanklin has raised is that if the over-all power factor of a length of cable does not increase appreciably during aging or operation, we need not be concerned with the radial power factor. This may not always be the case, however; for example, if we refer to figure 7 in Roper's paper previously referred to, we notice a small hump in the middle of the radial curve. In the early stages of aging this peak increased but not sufficiently to increase the power factor of the whole cable, yet it was the defects indicated by this hump which apparently caused failure. Then again, a cable does not always age uniformly in a longitudinal direction: in the vicinity of joints, reservoirs, and split lead sheath deterioration may go on concerning which the radial power factor method may give very useful information, of course only for post mortem purposes.

Shanklin is somewhat worried over the tendency of modern cables to become too pure. We find ourselves quite free from such worries as a result of testing modern cable oils, papers, and the finished product; many kraft cable papers contain 1 to 3 per cent lignins, resins, and other impurities which when extracted have a black tarry appearance and which catalyze oxidation of oil; inorganic material or "ash content" of cable papers runs 0.5 to 1.5 per cent. Most cable oils contain 0.1 to 0.5 per cent sulfur in addition to small amounts of oxidation products such as peroxides; we have also found traces of sulfuric acid esters in some cable oils, in addition to other impurities, and they contain considerable amounts of suspended material when seen under a Tyndall beam. The theorist who carries the idea of purity to extremes, we agree, is dangerous, but at present modern cables are so far removed from purity, even when no rosin is added, that there need not be the slightest worry on this score. Even were the cable pure, a little service would soon impart to it all those properties which Shanklin feels are so desirable for good life. We believe he has reference to petrolatum cable, the introduction of which was so disastrous some 10 or 12 years ago. The cause of this trouble was not so much that the petrolatum was too pure as that it had a set point in the operating temperature range of the cable. A contributing cause may have been the removal of all unsaturates from the petrolatum but we should not wish to call this purification, for a purified oil might well contain some stable unsaturates. By a pure cable oil we should refer to one from which most of the sulfur compounds, oxidation products, acid esters, and dirt had been removed. The theory that is cited, that if the oil and paper were made too pure the "wetting" properties and therefore the life would be impaired, has a good foundation; but, as we have pointed out, with present materials we need have no fear now nor probably for many years to come. We hardly believe that he would defend very strongly his statement that the only way to obtain a flat radial curve would be to use absolutely pure materials, since one or 2 manufacturers are getting very nearly flat curves at the present time, and moreover, this cable shows up very well on a load cycle test.

The statement that radial uniformity was a criterion of quality W. A. Del Mar feels was inaccurate, and that we should have referred to lack of erratic variation in radial power factor as a criterion. What he means is that if we have a cable insulated with 3 different density papers, each having different power factors, the radial power factor curves will not be flat but will resemble 3 steps. Although this might be a good cable the radial power factor would not be uniform. In practice, if good quality papers were used, the difference in power factor would be very small, and the height of the "steps" imperceptible. Nevertheless, his point is well taken. We have been concentrating so long on studies of cable with grossly irregular radial power factors such as those shown by Roper in figure 2 of his discussion that we had overlooked the possibility of a small stepped effect in graded cables. However, we do not feel we have transgressed seriously and we still think the term radial uniformity is desirable if these exceptions can be borne in mind.

We would not wish to see all other properties of cable sacrificed in order to get an absolutely flat radial power factor curve of low value and nowhere in our paper did we express such a point of view. We are glad Del Mar brought out the point, however. There seems to be considerable evidence that cables with badly erratic radial curves do not have as good a life in service. In his paper Roper has shown conclusively that the improvements in cable manufacture during the last 10 years have been accompanied not only by lower but by more uniform radial power factor (figure 4). He has also shown that small radial irregularities may indicate a weakness which will cause failure. We have some evidence also from load cycle tests that cables with uniform radial curves of low value have a better life than those with more irregular characteristics. Then again, now that many utility systems have reached a more stable stage where cable lines will not be continually cut over and rerouted, we must give more consideration to 20 and 30 year life. The gradual increases in dielectric loss, which appear from radial studies to go on continually in those solid type cables which have high radial power factors at sheath and conductor to begin with, may well reach such values at the end of 20 years that they will be an important factor in breakdown. We feel that this is true of many of the older 24 kv cables we operate if they were loaded at maximum permissible temperatures. Other factors being equal, then, cable with uniform radial power factor is the most desirable because it indicates, among other things, good housekeeping in the cable factories.

We refer Del Mar to our earlier paper (reference 1 of the present paper) where details of the radial method are fully covered. There we stated that the tapes are unwrapped from the cable and inserted in the cell for measurement. It seemed unnecessary to state that we did not wipe the oil from the tapes or subject them to any other treatment before inserting them in the cell; we do not think our omission of mention of all possible things that could have been done to the tape before measurement justifies the classification "uncertainty." The simple fact is, if the tape is removed immediately from the cable and inserted in the cell without excessive fingering as we mentioned, reliable results are obtained. We are pleased to learn of the greater accuracy that can be obtained at 1,000 cycles and we are pleased that Del Mar has again stressed the importance of eliminating end samples of cable from a reel if representative curves are to be obtained. Finally, we wish to call attention to an inaccuracy in his comments. He states that an error may occur if the thermometer is located some distance from the tape. We have gone over both our papers very carefully and fail to find any reference to a thermometer. In our original instrument we used a thermocouple located as close as practically possible to the paper tape. The accuracy was checked by inserting a thermocouple between the paper tapes during measurement. However, after an instrument has been calibrated and experience obtained with it, a thermometer may be inserted in the electrode and read directly, thereby saving some time.

The data presented by Roper both in his paper and in his discussion are exceedingly interesting and show the valuable information that can be obtained by the use of the radial method. They very strongly support the papers which we have presented. We are also very pleased that J. B. Whitehead has emphasized the use of our apparatus and method for general research purposes. We agree with him that where oxidation is reduced to the point where it is no longer the overshadowing factor, other causes of irregular radial power factor will be identified.

It has been reported that the brass electrodes of the cell for measuring power factor of paper tapes became covered with an invisible film of oxide after less than 2 hours at measuring temperature sufficient to affect the accuracy of the results. One investigator has eliminated this trouble by plating the electrodes with rhodium. Another caution that should be mentioned here is that it is advisable to wipe the excess oil from the electrode with a clean cloth quite frequently, otherwise the film of oil which remains on the brass becomes oxidized and may affect the results. This is a precaution which we have observed throughout our work.

News

Of Institute and Related Activities

50th Anniversary of First A-C System in America to Be Widely Celebrated

UP to January 20, 38 of the Institute's 61 Sections had signified their intentions of holding meetings on March 20 to celebrate the 50th anniversary of the establishment of the a-c system in America; 6 additional Sections expressed their willingness to co-operate fully in the celebration, although hampered by conditions peculiar to their specific programs. A few are able to meet the suggested date only approximately, and not all are able to devote their entire programs. That the response has been so general makes evident the appreciation of the importance of the event in engineering history and the possibilities of emphasizing the contributions of the electrical engineer to social progress.

The general plan, as announced previously, is to have one meeting in New York City directly under the auspices of a central committee, which is headed by A. W. Berresford (A '94, F '14, and past-president), and voluntary meetings of Sections or regions at or about the same time. The details of the New York meeting have not been finally determined, but are progressing rapidly. Details of the local or voluntary meetings rest entirely with the Sections themselves. Essentially, the purpose of these meetings is to pay reverence to the men who advanced the science, the engineering, and the industry, and to stimulate and energize the present generation by citing their accomplishments and the developments of the past. Also, it is thought that the occasion offers opportunity to point out the social and economic significance of these achievements to the audiences and to the public in the local communities.

The committee has made no attempt to develop set patterns or plans for meetings. Purely suggestively it is thought an interesting program could be developed upon the following basis:

1. A paper of an historic character dealing with the initiation and growth of the a-c system in each local area. The men, the successive steps, the data on power supply at different stages of regional growth, and other facts would be brought out.

2. A paper of a social and economic character, preferably in the form of an oration, that will depict the effects of the growth of the system either locally or nationally upon social and economic aspects of life. Rich local citations can be made as well as national contributions that are of the greatest significance to the welfare of humanity.

3. Honor all pioneers in the local industry by having them present and by giving brief citations of their careers and contributions.

Such a meeting, with or without a dinner, could be interesting, informative, and stimulating and is possible of attainment through local efforts.

Another suggestion embodies a modification of this first plan by importing, so to speak, an outstanding leader or pioneer to give a suitable address as one part of the program. This should be arranged through local initiative, but the committee will be glad to help and make suggestions as to speakers.

Another suggestion or modification is that younger engineers do the research and present the history of local electrical development each taking a particular field of activity for presentation. The remainder of the meeting then would embody a local or imported speaker or other variations.

Another modification suggested is that stress be given to the local historical development of the a-c system as exemplified in the outstanding local installations, for example, Niagara Falls, Boulder Dam, and New Haven Railroad electrification. This would give more time for presentation of the detail of the engineering and the history of the engineers involved. This feature could be supplemented by the second type of address.

The committee hopes that in the maximum degree possible the papers and addresses presented in local celebrations, and particularly those dealing with local development, will be put in manuscript form and transmitted to headquarters. If this is done universally, a mass of historical data not otherwise obtainable will be preserved for future record.

Summer Convention Plans Under Way at Los Angeles

Plans are well under way for the 1936 A.I.E.E. summer convention, which is scheduled to be held at the Huntington Hotel, Pasadena, Calif., June 22–26, 1936. This is the first time in the Institute's 52 years that the annual summer convention has been held on the Pacific Coast; the second time west of the Rocky Mountains (Salt Lake City, Utah, 1921). It is expected that the Pacific Coast membership will turn out en masse; and preliminary plans for special trains from the East are being formulated. More about this will be available in later issues of ELECTRICAL ENGINEERING.

According to Past Vice President R. W. Sorensen (to whose long-exerted untiring efforts are largely credited the decision to hold the next summer convention on the Pacific Coast) the Pacific Coast is "out to set a precedent" in connection with the forthcoming convention. Off to an early start, the following committee has been busy for the past 6 months or so: R. W. Sorensen, *chairman;* Fred Garrison, *assistant to chairman;* N. B. Hinson, *vice chairman;* O. W. Holden, *secretary;* J. C. Gaylord, *treasurer;* W. S. Peterson, technical program; G. A Riley, finance; E. L. Bettannier, transportation; H. L. Caldwell, housing; R. A. Hopkins, entertainment; R. F. Gheen, sports; F. B. Doolittle, publicity; F. C. Lindvall, student activities; Mrs. Mable Rockwell, ladies; David Hall, registration; G. P. Garman, inspection trips.

Middle Eastern District Executive Committee Meets

A meeting of the executive committee of the A.I.E.E. Middle Eastern District (Number 2) was held November 20, 1935, at the Bell Telephone Building, Pittsburgh, Pa. The following delegates attended: W. H. Harrison, vice president; H. A. Dambly, District secretary; H. L. Brouse, secretary, Akron Section; J. H. Lampe, secretary, Baltimore Section; L. L. Bosch, chairman, Cincinnati Section; F. E. Harrell, secretary, Cleveland Section; C. W. Fick, chairman, Cleveland Section; W. H. Reynolds, chairman, Erie Section; Edgar Bell, secretary, Lehigh Valley Section; H. C. Albrecht, past-chairman, Philadelphia Section; C. A. Powel, chairman, Pittsburgh Section; J. R. MacGregor, secretary, Pittsburgh Section; W. A. Sumner, chairman, Sharon Section; W. F. Brown, vice chairman, Toledo Section; and H. L. Curtis, chairman, Washington Section.

Vice President Harrison reported briefly on the objectives and standing of the membership efforts of the Institute. He presented figures from the report of the national membership committee submitted to the board of directors on October 22, 1935, showing 88 per cent paid up membership compared with 88.9 per cent in 1927 which was the best since 1920.

A general discussion on membership activities and problems of Sections throughout the District followed. Among the various items discussed were methods used by the various Sections to bring about reinstatement of delinquent members, various ways of building up Section membership, and sources of new members. The importance of the membership revenues to the Institute and the consequent importance of continued efforts to build membership were stressed.

In connection with the award of prizes for A.I.E.E. papers, it was pointed out that District prizes for any given calendar year shall be awarded prior to May 1 of the succeeding year by the District executive committee or by a committee appointed by the

District executive committee authorized to make such awards. Vice President Harrison was authorized to appoint a prize paper committee.

To serve on the District co-ordinating committee for the year ending June 30, 1936, the following were appointed: C. A. Powel, Pittsburgh Section; J. H. Lampe, Baltimore Section; L. L. Bosch, Cincinnati Section; Edgar Bell, Lehigh Valley Section; and A. H. Forman, West Virginia University, chairman of committee on Student activities. The District vice president and secretary are included also in the membership of this committee, in *ex-officio* capacities.

Details of the plan to celebrate the 50th anniversary of the establishment of the a-c system in America on March 20, were discussed. All Sections were urged to celebrate this occasion in a fitting manner.

W. E. Wickenden, president, Case School of Applied Science, Cleveland, Ohio, was elected as the District delegate to the national nominating committee.

The meeting was concluded by a discussion of matters of Institute policy and Section programs and activities. Delegates from various Sections outlined plans under way in their respective Sections. Several reported the planning of lecture meetings and inspection trips to local points of interest. One Section reported that a series of combined lecture and dinner meetings is proving popular. Another Section announced that a course in electronics would be available to members at an attractive rate. It was generally agreed that the best way to attract members to Section meetings is through good programs. To facilitate the planning of programs, a composite schedule of speakers and subjects for all Sections in the District is to be distributed through the Sections by the District secretary.

North Central District Executive Committee Meets

The annual meeting of the executive committee of the Institute's North Central District (Number 6) was held December 16, 1935, at the Telephone Building in Omaha, Neb. Those in attendance were: R. H. Fair, vice president; W. L. Cassell, chairman, Denver Section; W. C. DuVall, chairman, committee on Student activities; C. E. Winn, chairman, Nebraska Section; H. M. Craig, secretary, Nebraska Section; and T. H. Granfield, District secretary.

One of the principal subjects discussed pertained to the question of possible revision of Section boundaries in District 6. The committee voted unanimously to go on record as favoring:

1. That as a general principle all territory within the District be allocated to some Section.

2. That the boundary lines of Sections within the District conform to the natural trade areas of the respective Section headquarters.

3. That the Section boundary lines decided upon shall, in general, continue until such time as new Sections are added within the District, or other conditions make a change advisable.

4. That when new Sections are established within the District their boundaries be established in accordance with the foregoing.

The procedure to be followed in carrying out the allocation of territory to Sections in accordance with the foregoing action was a subject of considerable discussion. The consensus of opinion was that the members in the trade areas of the present Sections in the District not already affiliated with either Section should be asked to express their preference as to which Section they prefer to be included in.

Dean H. S. Evans of the University of Colorado, was unanimously chosen to represent the District on the national nominating committee. The vice president was authorized to appoint an alternate if Dean Evans is unable to attend the meeting of this committee.

The District committee on prize awards to act as judges in awarding prizes to the authors of papers presented at Section and Branch meetings during 1936 was selected. W. D. Hardaway of Denver was chosen to succeed himself as chairman; A. L. Turner was reappointed as representative of the Nebraska Section, and R. W. Lindsay was named the Denver Section representative.

Membership activities were discussed in some detail. The advantages of joint meetings with Student Branches were discussed, and some of the features that have been carried out in connection with these meetings were reviewed. It was pointed out that contacts between practicing electrical engineers and Student members obviously would assist in counteracting the tendency of Branch members to drop out of the Institute when they leave college. The executive committee endorsed Professor DuVall's plan for holding a District conference on Student activities at the University of Colorado in the spring of 1936 on a suitable date to be determined by him.

The desirability of beginning to plan for the meetings to celebrate the 50th anniversary of the establishment of the a-c system in America to be held next spring was pointed out, as neither the Nebraska nor the Denver Section is particularly well situated to arrange for a program of the type that the occasion seems to require.

Winter Convention to Be Reported in March Issue

As this issue goes to press, members and their guests have assembled in New York for the Institute's 24th annual winter convention. With a first day's registration of 602 compared with 633 in 1935 and 433 in 1934, and a second day's registration of 444, compared with 301 in 1935 and 433 in 1934, the outlook for a highly successful convention is excellent.

A full report of the convention and its various attractions is scheduled for inclusion in the March issue.

A Notable Gathering of Engineering Society Heads

THE growing importance of the engineer in public affairs and the necessity of calm, systematic thinking in politics and government were discussed analytically in a symposium "Ways That the Engineering Societies Can Serve" at a meeting of the Montclair (N. J.) Society of Engineers, January 3, 1936, in which the presidents of several engineering societies participated. In the group shown above are, left to right, front row: Admiral George H. Rock, president of the Society of Naval Architects and Marine Engineers, Arthur S. Tuttle, president of the American Society of Civil Engineers, and E. B. Meyer, president of the A.I.E.E.; back row: G. M. Lovejoy, president of the American Institute of Mining and Metallurgical Engineers, F. D. Herbert, president of the Montclair Society of Engineers, and W. L. Batt, president of the American Society of Mechanical Engineers.

1936 Year Book to Be Issued Soon

In accordance with the provisions of the 1935–36 budget as approved by the finance committee and the board of directors, the 1936 edition of the A.I.E.E. Year Book will be issued soon, in limited edition, but available to all members of the Institute who have use for it. In keeping with the established custom, copies of the Year Book will be distributed automatically to all national, District and Section officers, to Student Branch Counselors, and to all members of all national committees. Other members wishing to secure a copy of the 1936 Year Book should file written requests with the A.I.E.E. order department at 33 West 39th Street, New York, N. Y., giving correct mailing addresses.

The Year Book is not available to nonmembers of the Institute, nor is its use permitted for commercial, promotional, or other circularization purposes.

Since the issuance of the Year Book in the style adopted for the edition of 1934, a question has arisen as to what constitutes the most useful style and arrangement of the Year Book. Consequently, to settle this point prior to the issuance of the forthcoming 1936 edition, the publication committee circulated a questionnaire to all national, District, and Section officers, as well as to Student Counselors and members of national committees. The result of this poll was overwhelmingly in favor of the retention of the general style and arrangement adopted for the 1934 edition. Consequently, with but minor modifications designed to facilitate its convenient use, the 1936 Year Book will be issued in the same form and size as was the 1934 Year Book.

Accrediting of Colleges Begun by E.C.P.D.

The program of inspection and accrediting of engineering curricula, which the Engineers' Council for Professional Development offered last year to schools granting engineering degrees, has been accorded a hearty response by 34 colleges and universities in the New England and Middle Atlantic states. Inspections in these regions were begun late in 1935 and will be continued actively during the next few months. When substantial progress has been made in these areas, it is expected that the program will be extended to engineering schools throughout the United States. The accrediting program has for its purpose the best development of engineering education by identifying those institutions that offer engineering curricula worthy of recognition as such. The second objective is to build up a list of accredited engineering schools, which it is hoped may be adopted uniformly by educational, technical, and state organizations now using dissimilar lists.

Some 12 representative engineering institutions in the New England states and 22 in the Middle Atlantic states have applied for crediting. Some of these already have been visited by the delegatory investigating committees. The plan being followed in the accrediting procedure is that outlined in preceding issues of ELECTRICAL ENGINEERING (February 1935, pages 249–50; March 1935, page 343; and August 1935, page 895).

Future AIEE Meetings

North Eastern District Meeting,
New Haven, Conn., May 6–8, 1936

Summer Convention,
Huntington Hotel, Pasadena, Calif., June 22–26, 1936

South West District Meeting,
Dallas, Texas, Nov. 2–4, 1936

Southern District Meeting,
Birmingham, Ala., Dec. 1936

1936 Washington Award Goes to C. F. Kettering

According to a recent announcement, Dr. C. F. Kettering, vice president in charge of research, General Motors Corporation, Detroit, Mich., has been elected to receive the Washington Award for 1936. Selected from a field of some 26 candidates, Doctor Kettering receives the award "as an outstanding engineer who has rendered pre-eminent services in promoting the public welfare through his outstanding contributions to the increase of personal mobility and his driving force for the cause of research as an instrument to increase the welfare and happiness of all mankind." A biographical sketch of Doctor Kettering appears on page 218 of this issue.

The award, which consists of a suitable inscribed bronze plaque mounted upon a marble base, will be formally presented to Doctor Kettering at a dinner to be held in Chicago, Ill., on February 27, the time and place to be determined later. He is the eleventh noted American engineer to receive the Washington Award, since its foundation in 1916 by John Watson Alvord of Chicago.

The award is given annually, when deserving candidates are found, by the Washington Award Commission as "an honor conferred upon a brother engineer by his fellow engineers on account of accomplishments which pre-eminently promote the happiness, comfort and well-being of humanity." The commission is composed of 18 members, representing the following 5 engineering societies: The American Society of Civil Engineers, The American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, The American Institute of Electrical Engineers, and the Western Society of Engineers.

The award was the outgrowth of an endowment and a suggestion of Mr. Alvord in 1916 that there should be some means of recognizing outstanding engineers who render pre-eminent service in promoting the public welfare. The idea was proposed originally to the Western Society of Engineers, which soon invited the other societies to participate in the award. They accepted, and the award has since come to be recognized as one of the highest honors that can be conferred upon an American engineer.

The first award was conferred in 1919. Several years have intervened in which no award has been made because the commission discovered no candidate it deemed eligible for the high recognition. Previous recipients of the honor have been:

1919 Herbert C. Hoover (HM '29) "for his pre-eminent services in behalf of the public welfare."

1922 Robert W. Hunt, "for his pioneer work in the development of the steel industry and for a life devoted to the advancement of the engineering profession."

1923 Arthur N. Talbot, "for his life work as student and teacher, investigator and writer and for his enduring contribution to the science of engineering."

1926 John Watson Alvord, "for his pioneer work in developing the fundamental principles of public utility valuation and his marked contributions to sanitary science."

1927 Orville Wright (A '31), "for fundamental scientific research and resultant successful airplane flight."

1928 Michael Idvorsky Pupin (A '90, F '15, HM '28, member for life, and past-president), "for devotion to scientific research leading to inventions which have materially aided the development of long distance telephony and radio broadcasting."

1929 Bion Joseph Arnold (A '92, M '93, F '12, member for life, and past-president), "for pioneering work in the engineering and economics of electrical transportation."

1930 Ralph Modjeska, "for his contribution to transportation through superior skill and courage in bridge design and construction."

1932 William David Coolidge (A '10, F '34), "for his scientific spirit and achievement in developing ductile tungsten and the modern X-ray tube."

1935 Ambrose Swasey (HM '28), "for his distinguished contributions as a builder of instruments, institutions, and men."

Junior Award of A.S.M.E. At the recent annual meeting of The American Society of Mechanical Engineers held in the Engineering Societies Building, New York, N. Y., the Junior Award of the society was presented to S. J. Mikina, research engineer, of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. The award was based upon his paper "Effect of Skewing and Pole Spacing on Magnetic Noise in Electrical Machinery." Mr. Mikina has been with the Westinghouse company since graduating from the University of Michigan in 1930, and is now a member of the company's research staff, specializing in studies concerned with noise and vibration in electrical equipment.

Perkin Medal Presented. The Perkin Medal of the Society of Chemical Industry was presented to Warren K. Lewis, professor of chemical engineering at Massachusetts Institute of Technology, Cambridge, at a meeting of the society held on January 10, 1936. This meeting was held jointly with the American Chemical Society. The award to Professor Lewis has been made "in recognition of his creative activities as the father of modern chemical engineering, and his training of and inspiration to many of the present and potential leaders in the profession."

Columbia University Offers E.E. Scholarship

The governing bodies of Columbia University have placed at the disposal of the A.I.E.E. each year, a scholarship in electrical engineering in the school of engineering of Columbia University for each class. The scholarship pays the annual tuition fees of $380. Reappointment of the student to the scholarship for the completion of his course is conditioned upon the maintenance of a good standing in his work.

To be eligible for the scholarship, the candidate recommended will have to meet the regular admission requirements, in regard to which full information will be sent without charge upon application to the secretary of the University or to the national secretary of the Institute, 33 West 39th Street, New York, N. Y.

In a letter addressed to the national secretary of the Institute, an applicant for this scholarship should set forth his qualifications (age, place of birth, education, references to any other activities, such as athletics or working way through college, reference, and photograph). A committee composed of W. I. Slichter, *chairman*, Francis Blossom, and H. C. Carpenter will consider the applications and will notify the authorities of Columbia University of their selection of a candidate. The last day for filing of applications for the year 1936–37 will be June 1, 1936.

The course at the Columbia school of engineering is a graduate course which may be either elective leading to the degree of master of science or prescribed leading to the degree of electrical engineer. For the former, requirement for admission is the completion of 4 year course in electrical engineering as evidenced by a bachelor's degree from an approved institution. For the professional degree, the requirements are more specific as to course content and include a considerable proficiency in mathematics, physics, and chemistry, and some knowledge of the humanities, as well as the usual undergraduate technical courses. The candidate is admitted on the basis of his previous collegiate record, without undergoing special examinations. Other qualifications being equal, members of the Student Branches of the A.I.E.E. will be given preference.

The purpose of this advanced course is to produce a high type of engineer, trained in the humanities as well as in the fundamentals of his profession. It is hoped that Enrolled Students and others qualified will show a keen interest in this scholarship.

Pamphlet on The Earth's Magnetism. A publication of the Coast and Geodetic Survey of the U.S. Department of Commerce, gives a sketch of the development of knowledge relating to the earth's magnetism, describes the methods and instruments used in its measurement, sets forth some of the important results of magnetic surveys and operation of magnetic observatories, outlines some of the theories advanced to account for the earth's magnetism and its changes, and points out how closely it is related to earth currents, atmospheric electricity, solar activity, and auroras. This publication, entitled "The Earth's Magnetism," is special publication No. 117, issue of 1925, of the Coast and Geodetic Survey, and may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents each.

Gaston Planté Medal to Be Established. The Société Française des Électriciens has announced the institution of a "Gaston Planté Medal," consisting of a silver-gilt medal to be awarded every 3 years and accompanied by a sum in cash of 4,000 francs, this medal to be awarded any person regardless of nationality, who makes an important contribution in the fields of electric storage batteries, voltaic cells, or electrochemistry in general. The electrotechnical societies and committees of each country may propose a name to the commission of awards. The names of candidates, together with their publications (accompanied by a French translation whenever possible) should be sent to the commission of award at least 6 months before the award of the medal. The first award will take place in June 1937. All correspondence relative to the Gaston Planté Medal should be addressed to the president of the Société Française des Électriciens, 14 avenue Pierre Larousse, Malakoff (Seine), France. Announcement of the celebration of the centenary of Gaston Planté, who contributed much to the early development of the storage battery, was given in ELECTRICAL ENGINEERING for July 1933, page 508.

Bibliography on Vibration in Electrical Conductors

A revised bibliography on vibration, fatigue, and associated phenomena in electrical structures has been prepared under the auspices of the A.I.E.E. power transmission and distribution committee. Since more than 2,350 references are included in the work, it is more inclusive than previous issues, the first of which was completed in 1932, and the second in 1933.

Although only about 100 copies of the bibliography are available, an effort is being made to place a copy in the hands of each individual or organization recognized as studying the subject extensively. It is suggested that members interested in receiving a copy should write to either C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y., or the compiler, A. E. Davison, c/o Hydro-Electric Power Commission, secretary, A.I.E.E. power transmission and distribution committee, 620 University Avenue, Toronto, Ontario, Can.

220 Kv Underground Cable. In Paris, France, there has been installed a 3-phase 220-kv underground cable, designed to carry a load of 160,000 kw and tieing together 2 substations of the Inter-Paris Societe d'Electricite de Paris and Union d'Electricite. The cable employed is of the oil-filled single-core Pirelli type; it has a copper section of 0.55 square inch and an over-all diameter of 3.35 inches.—*Electrical Digest.*

A.S.T.M. to Meet in Pittsburgh. On March 4, 1936, the American Society for Testing Materials will hold a regional meeting at the Hotel William Penn, Pittsburgh, Pa. The meeting will consist of a symposium on high-strength constructional metals comprising 5 papers dealing with copper, aluminum, and magnesium alloys, nickel and its alloys, carbon and low-alloy steels, and corrosion-resisting steels.

Membership—

Mr. Institute Member:

As of January 2, 1936, there have been received applications for membership in the Institute to the number of 522 since May 1935, whereas in the corresponding period last year the number was 468. This represents an increase in applications for membership of 11.5 per cent over last year.

This is due to your participation in sending in names of those you think should be invited to join the Institute and to the wonderful work of the Section membership committees in carrying on continuously with the contacting of new members, the working with former members toward reinstatement, and the bringing of Enrolled Students to Associate membership.

Those good results are yours as you continue to send in new member prospect names to the chairman of your Section membership committee.

Everett S. Lee

Chairman National Membership Committee

Westinghouse Company Celebrates 50th Anniversary

To celebrate its 50th anniversary, the Westinghouse Electric and Manufacturing Company gathered together its employees in special meetings held simultaneously on the evening of January 8, 1936, in cities where the company is represented by factories, offices, warehouses, subsidiaries, or dealers. This date was exactly 50 years from the date in 1886 when the company was granted its original charter "for the manufacture of electrical products." The headquarters anniversary meeting was held in Pittsburgh, Pa., and provided the key program for all other meetings. The celebration was featured by addresses by A. W. Robertson (A'27) chairman of the board, and F. A. Merrick (A'07) president. Short-wave radio communication was used to link together this country-wide celebration.

In his remarks, Mr. Merrick said, speaking of the company's original charter: "The real charter under which Westinghouse Electric was founded is the spirit of progressiveness, courage, integrity, and humanity, under which it has forged ahead to its eminent position of service in our modern life."

Mr. Robertson outlined some of the high lights in the history of the company, which parallels very closely the history of the electrical industry in general. He illustrated the tremendous advances made in the application of electricity to everyday life by drawing vivid contrasts between the situation in 1886 and that in 1936. He emphasized the many contributions that the Westinghouse company has made to the development of the electrical industry, many of which were pioneering efforts over unchartered ways.

Speaking of the fundamental contribution that Westinghouse has made in the establishment and subsequent development of the a-c system, Mr. Robertson said: "The present universal use of alternating electric current is due in no small measure to the prophetic vision of George Westinghouse. It took courage to oppose the great Edison but Mr. Westinghouse was not lacking in courage. The Westinghouse organization has never lost the spirit of courage, enthusiasm, and foresight instilled into it from the day of its birth by its founder. These traits are basic elements in the character of the institution. No one could visualize a Westinghouse organization without them."

Mr. Robertson described also the part that the Westinghouse company played in the development of hydroelectric power at Niagara Falls, its early promotion of the steam turbine, its pioneering efforts in radio broadcasting, and many other advances in the field of electrical machinery, electrical transportation, and the generation, transmission, and distribution of electric power.

Speaking of the past with respect to the future of the company, Mr. Robertson said: "Westinghouse has survived for more than 2 generations because it deserved to survive, and for no other reason. The company has served the world well and the world has rewarded it well. The past is an open book. We of the present read it with pride and with due respect for the accomplishments of the past. The future lies before us unknown. The destiny of the Westinghouse Electric Manufacturing Company is now in our hands. If the past history was great, it was great because the men of Westinghouse were great men. If we have a great future, it will be for the same reason, namely, that the men of Westinghouse are great men. They must have courage, industry, and foresight. . . .

"It is useless to point to the past with pride. The key of the past will not open the door of the future; but continued application of courage, enthusiasm, and foresight will carry Westinghouse to heights beyond our imagination. Westinghouse men have raised the banner of the Westinghouse company high. It is our duty and privilege to keep it high."

Electric Shovel Handles 50 Tons at One Scoop

With the ability to pick up a 50 ton load at one scoop and place it on top of an ordinary 6 or 7 story office building, this power shovel recently was placed in service in coal stripping operations by the Northern Illinois Coal Corporation. The machine was built by the Marion Steam Shovel Company, Marion, Ohio, and its electrical equipment was furnished by the General Electric Company, Schenectady, N. Y. One outstanding feature of the machine is its immense dipper, which measures $9^2/_3$ by $8^1/_3$ by $16^1/_3$ feet, and which has a rated capacity of 32 cubic yards, or approximately 40 cubic yards heaping full. The dipper is fabricated from aluminum plates and castings, with an armor of special wear-resisting steel at the points. The boom is more than 100 feet long and the dipper handle more than 65 feet in length. Despite its size and capacity, one complete cycle of operation can be accomplished in from 45 to 50 seconds, which will enable the shovel to move more than 1,000,000 cubic yards of material per month. The shovel is driven by electric motors, and the equivalent ratings of all motors and generators on the machine total more than 3,500 horsepower. The shovel is controlled by newly developed magnetic equipment.

Editor and Engineer F. R. Low Dead at 75

Fred R. Low, an international figure in journalism and engineering, died at 6 a.m., January 22, at his home in Passaic, New Jersey, where he had been critically ill for several years. He was 75 years old.

A self-made man, whose formal schooling stopped as a result of severe illness when he was 14, Mr. Low achieved wide recognition as an engineer and technical editor. At the time of his death, he was editor emeritus of the engineering journal *Power*, following 42 years (1888–1930) as its chief editor. He was a past-president (1924) of the American Society of Mechanical Engineers, former mayor of Passaic, honorary member of the British Institution of Mechanical Engineers and honorary doctor of engineering, Rensselaer Polytechnic Institute.

At the time of his death, Mr. Low was still chairman of 2 important A.S.M.E. committees, dealing respectively with the codification of safety rules for the construction of steam boilers and unfired pressure vessles, and the rules for testing boilers, turbines, engines, and other power equipment.

Mr. Low was an honorary member of the National Association of Practical Refrigerating Engineers and of the National Board of Boiler and Pressure Vessel Inspectors; a member of the National

Association of Power Engineers, the Vereines Deutscher Ingenieure, the Newcomen Society, the Engineer's Club of New York, and long active in several civic and fraternal organizations. He was past-president of the Passaic City Club.

Mr. Low was noted for his unobstrusive friendliness, his simple directness and practicality in speech and writing, and his rich fund of humor. He was a man of few words, but these notable.

N.E.M.A. Standards for Power Switching Equipment

The National Electrical Manufacturers Association has just released a new publication entitled, "NEMA Power Switching Equipment Standards," publication 35-28, which supersedes the power switching equipment section of the "NEMA Switchgear Standards," Number 31-10, published in 1931. This is the first of a series of publications which will supersede the various sections of the switchgear standards.

The new power switching equipment standards contain many new standards among which are several covering insulator units, such as rating, basis of rating, and flashover values for insulator units ranging in voltage from 7.5 to 220 kv. Several new standards for testing insulators have been added, comprising standards for cantilever, tensile, compression, and torsional strength. A separate section on definitions of terms is included. A section also is devoted to installation and care, and operation of power switching equipment.

The publication consists of 48 pages with an index and is 8 by $10^1/_2$ inches in size. Copies may be obtained at 75 cents each from the N.E.M.A., 155 East 44th Street, New York, N. Y.

Iron and Steel Electrical Engineers Elect Director

The board of directors of the Association of Iron and Steel Electrical Engineers recently elected Brent Wiley to serve as managing director of that society. He succeeds the late J. F. Kelly.

Mr. Wiley graduated from Rose Polytechnic Institute, Terre Haute, Ind., in 1898, with the degree of bachelor of science in electrical engineering, later being awarded the degree of master of science. He has been closely associated with the steel industry for the past 37 years.

After leaving college, he spent one year in the electrical department of the Ohio works of the Carnegie-Illinois Steel Corporation, later going to the Homestead works of the same company as the assistant to the electrical superintendent. In 1904, he went with the Wellman-Seaver-Morgan Company in Cleveland, Ohio, as electrical engineer, and in 1906 became associated with the Westinghouse Electric and Manufacturing Company, where he remained for the next 25 years. Here he was concerned principally with the development of the electrification of the steel industry.

American Engineering Council

Sixteenth Annual Meeting Held in Washington, D. C.

THE sixteenth annual meeting of American Engineering Council was held in Washington, D. C., on January 10 and 11, 1936. Delegates from the 42 member organizations discussed the growing evidence of unity in the profession as to the formulation and dissemination of opinion on matters of public affairs. The assembly acted upon reports from 16 major and minor committees and subcommittees of the Council, listened to stimulating addresses at the "all engineers dinner," attended by some 450 engineers, and left Washington with renewed expressions of the opportunities for advancing the public interest and for maintaining high professional standards through the agency of A.E.C. A report of the meeting, as furnished by Frederick M. Feiker, executive secretary, follows.

At the morning session at the Mayflower Hotel, January 10, President J. F. Coleman opened the meeting with an address on the essential elements in reviving the construction industry. Then followed in order a series of reports and discussions covering a wide range of subjects of timely interest to engineers.

Survey of the Profession

George T. Seabury, chairman of the engineering and allied technical committee, reported on the preparations made for the "Survey of the Engineering Profession" conducted by the bureau of labor statistics of the U.S. Department of Labor. Dr. Isador Lubin, chief of the bureau, reported extensively, basing his remarks on returns from more than 60,000 questionnaires, the largest survey of this kind ever conducted. He indicated that the findings would tend to give direction to engineeringe ducation, to choice and distribution of occupation, and to compensation of engineers. It is expected that full returns will be available in the early spring. It was voted to recommend to the executive committee of Council that steps be taken toward private publication of a mass of detailed information to supplement the government report.

Dr. Leonard D. White, U.S. civil service commissioner, discussed the needs for a widely extended civil service to include state and local governmental bodies as well as federal, in order to uphold the professional standards of engineers in the public service. Discussion developed that classification by position is essential in the development of a suitably paid civil service. It was voted to instruct the executive committee to take the steps necessary to put these basic concepts into action, especially in co-operation with local and state engineering societies.

Economic Balance Toward Higher Standards

Ralph E. Flanders presented the third progress report of the committee on the interrelation of production, distribution, and consumption. In 108 classified questions and answers, there was presented a catechism on the engineers' concept of the possibilities of an economic balance in the interests of a high standard of living for all. The report was accepted with the recommendation of the committee that all delegates study it, secure local discussion on its major objectives and detailed recommendations, and report back February 1, with the plan of presenting the report publicly as soon as possible thereafter as the engineers' contribution to the national welfare.

Charles W. Eliot, II, executive officer of the national resources committee, discussed the purposes and plans of that body in forwarding a state and local as well as a federal concept of planning. The need of approaching planning from a local and regional viewpoint was especially emphasized. It was voted to refer the bill (S. 2825) now before the Senate, providing for the continuation of the federal organization on a permanent basis, to the public affairs committee of Council for recommendations.

Public Affairs Reports

The public affairs committee, under the chairmanship of F. J. Chesterman of Pittsburgh, has been organized under a new plan during the past year with several subcommittees active in studying public problems which fall within the purview of the profession. For co-ordination, the subcommittee chairmen are members of the national committee and steps are being taken to make the membership of subcommittees overlap with that of similar committees of national, state, and local engineering societies. As a result of this work, the reports rendered at the annual meeting cover basic findings in a broad variety of fields.

The subcommittee on the administration of public works, F. M. Gunby, chairman, reaffirmed Council's past position that engineering public works of the federal government, in so far as practicable, should be concentrated under one qualified head.

The water resources committee, headed by W. S. Conant, reiterated its belief in 2 fundamental needs for the formulation of a water resources policy: (1) complete and co-ordinated basic data bearing on the subject, and (2) comprehensive study of water control legislation. The establishment of a body similar to the board of surveys and maps of the federal government for the correlation of government data on water resources was recommended.

As a result of the work of the aeronautics subcommittee, headed by Grover Loening, the public affairs committee adopted a report supporting aeronautical research by the colleges, disfavoring further investigations of the industry, recommending further studies toward the simplification of aircraft construction regulations, and favoring

the placement of employees of the bureau of air commerce under civil service.

The committee on competition of government with engineers in private practice, under the chairmanship of Alonzo J. Hammond, advocated the curtailment of competitive activities by government and the raising of consulting fees by public bodies to a basis comparable with private practice.

Rural Electrification

R. W. Trullinger of the U.S. Bureau of Agricultural Engineering reported on the activities of a subcommittee, made up of members of the American Society of Agricultural Engineers, a member body of Council, to forward the rural electrification program through the aid of engineers. It was voted that this work continue under a committee representative of the profession as a whole.

The assembly received a report of the committee on patents, Dean A. A. Potter, chairman, dealing with the elimination of fraudulent practices, the use of a single signature on patent applications, the validation of joint patents, and the extension of the full rights of inventors. In addition, several specific items of legislation were presented as under consideration by the committee. It was recommended that the work of the committee be continued.

Mapping

The assembly adopted the recommendations of the executive committee that Council establish a new committee on mapping and surveys and that it endeavor to organize public opinion as to the basic need for completing the map of the United States. It was voted to support the original Temple Act to the end that its purposes be effectuated by appropriations based upon the fundamental values of mapping and not on a relief basis.

All Engineers Dinner

The annual all engineers dinner of Council, held on the evening of January 10, filled the main ballroom of the Mayflower Hotel. Some 450 engineers, representing all the major branches of the profession, were in attendance. Dr. Harrison E. Howe, editor, *Industrial and Engineering Chemistry*, proved a brilliant toastmaster.

Following the dinner, an engrossed resolution was tendered to J. F. Coleman in appreciation for his services as president of Council during the past 2 years. Dr. William McClellan, president of the Potomac Electric Power Company and chairman of the dinner committee, made the presentation. He told how Mr. Coleman had been successful in carrying Council through a critical period in its history. Dean A. A. Potter was introduced as the new president of Council. He stressed the need for solidarity of engineering opinion.

Dr. William F. Durand, chairman of the Third World Power Conference, past-president of The American Society of Mechanican Engineers, and John Fritz Medalist for 1935, discussed the deeper functions of the engineer. He stated that engineers are the custodians of natural resources such as minerals, coal, and oil but are not fully living up to their responsibility in conserving these resources. The profession, he said, must concern itself not alone with technical matters, but increasingly with human and social problems.

Ralph E. Flanders, past-president of the A.S.M.E., directed his remarks toward a reply to a recent address by Walter Lippman before the American Medical Society. Mr. Lippman had stated that the engineer is a master of material resources, but that the application of his material concepts do not work in solving human problems. Mr. Flanders stated that on the contrary every phase of the engineer's work is intensely human in its application and relationships. He predicted that engineering technique will carry the nation far beyond the "miserable physical standards of 1929."

The meeting was addressed also by the presidents or secretaries of each of the 7 national engineering societies holding membership in Council, and by the chairman of the sixth conference of the secretaries of engineering societies. Those present were unanimous in affirming their support to the continued leadership of Council as a unifying influence in engineering affairs.

New Officers

Council's new president for 1936 and 1937 is Dr. A. A. Potter, dean of the schools of engineering, Purdue University, who succeeds J. F. Coleman of New Orleans. New vice presidents are: Ralph E. Flanders, president of the Jones and Lamson Machine Company, for a 2 year term; and J. S. Dodds, professor of civil engineering, Iowa State College, for a one year term.

The chairman of the public affairs committee and of the committee on membership and representation were made *ex-officio* members of the executive committee of Council. The present public affairs chairman is F. J. Chesterman. C. O. Bickelhaupt, who heads the membership group, already is a member of the executive committee as vice president of Council. In addition to these, the executive committee includes Alonzo J. Hammond, vice president, C. E. Stephens, treasurer, and William McClellan, chairman of the finance committee, who were re-elected. Frederick M. Feiker was re-elected executive secretary.

Secretaries' Conference

Preceding the meeting of the assembly of Council, there was held on January 9 the sixth conference of secretaries of engineering societies. Some 30 national, state, and local societies were represented. The morning program developed the possibilities and opportunities for co-operation and co-ordination on matters of public affairs through state societies, national societies, and the A.E.C.

Both at this session and at the subsequent Council session on public affairs, the development of local and state public affairs committees was carried forward and both meetings favored the further co-operation of present organizations to develop united action in these matters.

Speakers at the secretaries' conference included: J. F. Coleman, on "Progress in Engineering Organization"; General R. I. Rees, of New York, on "Opportunities for Unity Among Engineering Organizations"; and Col. J. M. Johnson, assistant secretary of commerce, on "The Engineer in Government and Business." Other topics included co-operation with national, state, and local secretaries; employment activities; engineering publicity; nontechnical programs; and engineering society management.

On adjournment of the secretaries' conference, an informal tea and reception was held at the home of Mr. and Mrs. F. M. Feiker in honor of Mr. and Mrs. J. F. Coleman and Dean A. A. Potter.

Engineering Foundation

New Appointments to Alloys of Iron Committee

Appointment of 3 representatives of the steel industry to the alloys of iron research committee of the Engineering Foundation, which is carrying on world research embracing the entire body of knowledge of steel, alloy steel, alloy iron, and cast, wrought, and pure iron, is announced by the director of the Foundation, Dr. Alfred D. Flinn. Dr. John Johnston, director of research of the United States Steel Corporation, was named to the committee to represent the American Iron and Steel Institute. Wilfred Sykes (A'09, F'14) a director of the Inland Steel Company, becomes a member-at-large, succeeding the late Dr. John A. Mathews, who was vice president of the Crucible Steel Company of America. The other new member is James T. Mackenzie, metallurgist and chief chemist of the American Cast Iron Pipe Company, who takes the place of R. E. Kennedy, technical secretary of the American Foundrymen's Association.

Wide advances in the use of alloys were reported by the Foundation as the result of the scientific investigations being conducted in laboratories in many countries. "Interest in these ferrous metals is growing rapidly and use is increasing through spread of knowledge of their properties," said the report, pointing out that the Foundation's critical survey will go forward in 1936 with the support of American science and industry and of metal experts in many countries.

Nearly 150 men, including some of the world's foremost specialists in alloy steels, physical and works metallurgists, physicists, chemists, engineers, and superintendents of alloy steel plants, are co-operating with the committee, of which Prof. George B. Waterhouse of Massachusetts Institute of Technology is chairman. The committee's collection of classified abstracts now numbers 15,300, with those in foreign languages translated into English. Already, 6 monographs have been issued, 9 are in preparation, and 5 more are planned. The work, on which about $125,000 has been spent, is described as "the most extensive search of a branch of technical literature ever undertaken" and "the most comprehensive, if not the only collection of such data in the world."

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

The Moffat Process for Producing Steel

To the Editor:

The article "Industrial Electrochemistry Advances" by Colin G. Fink in the September, 1935 issue of ELECTRICAL ENGINEERING (pages 920–3) refers to what is called a "new" furnace, developed by T. F. Bailey of Alliance, Ohio, for the production of steel direct from ore. In the description of the furnace it is said that "the upper part of the furnace resembles a small shaft furnace. Reducing gases (largely carbon monoxide) pass upward through this heated shaft and finely divided iron ore particles pass downward. The particles thus are reduced to metal which drops into the electric furnace forming the base of the shaft. Here, with the aid of the electric arc, the metal droplets are converted into high grade steel."

As a matter of record it should be noted that such shaft furnaces for the direct reduction of iron ore are not new, but that a furnace of the same type, invented by J. W. Moffat of Toronto, was in operation for some years in the Moffat-Irving Steel Works, Toronto, about 20 years ago. While the original patents have thus expired and the principle is open to exploitation by anyone, credit should be given to the original inventor.

The interested reader is referred to the *Iron Age*, October 15, 1914; November 18, 1915; and *Canadian Machinery*, December 31, 1914, for descriptive matter on the Moffat-Irving process. The following paragraph from the article in *Canadian Machinery* shows the essential similarity.

"The idea occurred to Mr. Moffat to reverse the condition of the blast furnace, and instead of making the gas pass through the more or less dense body of descending material, reduction could be obtained by passing a shower of fine ore through a body of hot ascending gases... After preliminary trials had been made on a small scale in the laboratory, a 300 kw furnace was built to meet commercial conditions by the Moffat-Irving Steel Works at Toronto."

Blast furnace flue dust was first used, later magnetite concentrates were successfully smelted, commercial steel being produced of high quality.

Financial troubles due to war conditions prevented the continuance of the process on a commercial scale. Later Mr. Moffat and the writer undertook an extensive research into the problems of iron ore reduction without fusion and established the series of reactions which occur between hematite or magnetite, carbon, and the reducing gases. Another process was devised of sufficient merit to become a serious competitor of the blast furnace for ores requiring beneficiation. The approaching exhaustion of high grade hematite deposits will no doubt focus attention on electric smelting once more.

Yours very truly,

W. F. SUTHERLAND

171 Dawlish Ave.,
Toronto, Ont., Canada.

Editor's Note. In reply to a request as to whether or not the Moffat process is in use today, the following reply was received from Mr. Sutherland: "No, there is no commercial application of the Moffat process in operation today. Several reasons have prevented commercial exploitation. Mr. Moffat died some years ago and the major driving power toward commercialization was thus lost. Further, while the process has undeniably attractive features, its chief economies will be most evident in the treatment of magnetic and other ones requiring beneficiation, and until the Lake Superior ranges are more nearly exhausted the industry in general will be loath to change over to new methods, particularly in view of the immense amount of capital tied up in existing plant. This situation holds for Canada as well as the United States, since central Canada depends on the United States for its ore at present.

"Again, as is evident, the last few years have not been favorable to the promotion of new industries, either from the standpoint of financing or that of markets. I rather feel, however, that there should presently exist an opportunity for the application in a small way of the Moffat process for steel foundry work."

Registration of Engineers

To the Editor:

In a letter published in the December number of ELECTRICAL ENGINEERING a member from Buffalo criticized my letter in the October number, quoting me as speaking of the " 'intolerable burden on this country' which would be created by the registration of engineers as well as how 'unbearably oppressive' as is such a movement." Had I made such a statement it certainly would lend itself to such ridicule as he has applied to it.

What I actually said was: "No one regulatory activity of this kind can be said to be unbearably oppressive, but in the aggregate the bureaucratic organization thus created is becoming an intolerable burden on this country." In view of the regulatory activities of the present adminstration I consider the foregoing to be a very mild statement.

Removing phases from their context and quoting them in such manner as to distort their meaning is a favorite device in certain types of arguments, but the ethics of the profession, whether legalized or not, should keep such tactics out of discussions on engineering problems.

I believe that the various engineering societies would render their members a very valuable service by taking a referendum on this subject in connection with their annual elections. A summary of the reasons for and against registration should be given in the official publication of each organization immediately preceding the election. If the vote were in favor of registration, those who are opposed to it would be relieved of the feeling that it has been imposed on them by a minority of the profession. If the vote were against registration, the influence of the organization should be used to secure modification or repeal of existing legislation.

Very truly yours,

H. T. FAUS (A'24, M'34)

61 Nahant St.
Lynn, Mass.

Calculating Power Factor in a 3 Phase Circuit

To the Editor:

When calculating the power factor in a 3 phase circuit, the method most commonly used is to get the ratio of the power to the volt-amperes. In a balanced 3 phase circuit using the 2-wattmeter method the power factor may be obtained from the wattmeter readings by the formula

$$\tan\theta = \frac{\sqrt{3}(w_2 - w_1)}{(w_2 + w_1)} \tag{1}$$

Equation 1 is a common form appearing in textbooks but it requires curves or tables to obtain the cosine value corresponding to the tangent value. A simple form giving direct results may be had from the above as follows:

Squaring both sides, there results:

$$\tan^2\theta = 3 \times \left(\frac{w_2 - w_1}{w_2 + w_1}\right)^2 \tag{2}$$

But

$$\tan^2\theta = \sec^2\theta - 1 = \frac{1}{\cos^2\theta} - 1$$

Substituting in equation 2, there results:

$$\frac{1}{\cos^2\theta} = 1 + 3\left(\frac{w_2 - w_1}{w_2 + w_1}\right)^2 \tag{3}$$

Simplifying,

$$\cos\theta = \frac{1}{\sqrt{1 + 3\left(\frac{w_2 - w_1}{w_2 + w_1}\right)^2}} \tag{4}$$

Letting $(w_2 - w_1)$ = difference = d
Letting $(w_2 + w_1)$ = sum = s

and multiplying the right hand side by 100 there results, from equation 4:

Power factor (in per cent) =

$$\frac{100}{\sqrt{1 + 3\left(\frac{d}{s}\right)^2}} \tag{5}$$

Equation 5 is simple, easily remembered, and does not require any curves or tables.

Very truly yours,

JOSEPH A. BALOMBIN (A'33)
Cleveland (Ohio) Electric Illuminating Co.

Installations of Hochstadter Pressure Cable

To the Editor:

I would call attention to an error in Dr. J. B. Whitehead's admirable summary entitled "Recent Progress in Dielectric Research" in ELECTRICAL ENGINEERING for December 1935, pages 1288–91. In the last paragraph but one he mentions that a 50-kv oil-filled cable with submarine section, is reported from Copenhagen.

The recent Copenhagen cable is not of the oil filled type. It is a Hochstadter pressure cable, wherein a lead-sheathed paper cable is enclosed in a steel pipe containing inert gas at a pressure of 200 pounds per square inch. This cable was installed in 1934 and, as Dr. Whitehead states, has a submarine section which is about 1,000 feet long. I had the privilege of witnessing the installation of this cable and its pipe and can testify to a fine engineering job by the Felten and Guilleaume Company and associated contractors. This line has been in successful operation at 50 kv with an insulation thickness such as would be used on ordinary cable of $^1/_2$ this voltage. The gas pressure has not decreased, although the pipe is not connected with any reservoir of gas. The total installation is about 8 miles long.

As the result of this successful installation and the equally successful one between Hackney and Walthamstow, in London, England (installed 2 years previously), several other lines have been contracted for, notably at Oslo, Stettin, and other European cities.

Very truly yours,

WM. A. DEL MAR (A'06, F'20)
Chief Engineer, Habirshaw Cable and Wire Corp., Yonkers, N. Y.

Personal Items

C. F. KETTERING (A'04, F'14) vice president and director of General Motors Corporation, and general director of the General Motors Research Laboratory, has been elected to receive the Washington Award for 1936. Details of the award are given on page 212, this issue. Doctor Kettering was born on a farm near Loudenville, Ohio, on August 29, 1876, where he obtained his early education. After some further training at Ohio Normal School, and Wooster University, he taught for a while in a country school, later entering the employ of the Star Telephone Company, Ashland, Ohio, as installation man, of which company he became chief engineer in 1898. In 1900, Doctor Kettering entered Ohio State University where he studied electrical engineering. After graduating in 1904, he became electrical engineer and head of the department of electrical inventions of the National Cash Register Company, Dayton, where he developed electrical credit systems for department stores, electrically driven cash registers, and several types of electrically controlled accounting and auditing machines. In 1910, he, together with Edgar A. Deeds, organized the Dayton Engineering Laboratories Company (Delco) with headquarters at Dayton, Ohio, for the purpose of manufacturing one of Doctor Kettering's most important inventions, the starting, lighting, and ignition system for automobiles, and later farm lighting systems. In 1916, he established a research laboratory at Dayton to work on several problems of considerable interest and seeming merit. This laboratory was taken over by General Motors Corp. in 1920, and in 1925 it was moved to Detroit and combined with other research operations of the corporation. This group of engineers and scientists still functions under Doctor Kettering's supervision. Doctor Kettering is the patentee or co-patentee of approximately 140 inventions. His genius and inventive ability enabled him during the World War to contribute in many ways to the electrical, mechanical, and aeronautical departments of the service. In addition to the offices already mentioned, he is vice president of the Frigidaire Corporation; vice president of the Delco-Light Company; president and director of the Flexible Company; director of the Uplands Realty Company, Inc.; president and director of The Domestic Building Company; director of the Moraine Development Company; director of The Winters National Bank and Trust Company; and trustee of Antioch College. He was a member of the Institute's first Lamme Medal committee, 1928–29. He is one of the founders of the Engineers' Club of Dayton, Ohio, and is, in addition, a member of the following societies: Society of Automotive Engineers, American Society of Mechanical Engineers, American Society for Testing Materials, American Society for Metals, American Academy of Social and Political Science, American Philosophical Society, American Physical Society, American Academy of Science, American Association for the Advancement of Science, National Academy of Science, Society of Military Engineers, American Chemical Society, National Gas Engine Association, Detroit Engineering Society, Dayton Engineers' Club, the Army and Navy Club, Detroit Yacht Club, and New York Yacht Club. He is also a member of Sigma Xi and Tau Beta Pi, honorary fraternities. In 1929, he was awarded the Sullivant Medal, given every 5 years by Ohio State University to the alumnus who has achieved noteworthy results in science, engineering, literature, or the social sciences. Honorary degrees have been conferred upon him by 8 different colleges and universities.

WILLARD CHAMPE (A'25, M'35) since August 1, 1931, an assistant editor on the staff of ELECTRICAL ENGINEERING resigned as of January 15, 1936, to join the electrical engineering staff of the Consumers Power Company, Jackson, Mich. Mr. Champe is a native (1901) of Toledo, Ohio, where he received his early schooling; an electrical engineering graduate (1923) of the University of Michigan, Ann Arbor. After 8 months with the Westinghouse Electric and Manufacturing Company, at East Pittsburgh, Pa., where he was on the graduate student course and in attendance at the company's engineering school, Mr. Champe joined the engineering staff of the Commonwealth Power Corporation of Michigan, Jackson, remaining with that organization and its successor, Stevens and Wood, Inc., until February 1930. His first 5 months were spent in the electrical drafting room, engaged on power station and substation layouts and wiring diagrams, after which he served a year as assistant head of the switchboard engineering department, writing specifications for equipment, and responsible for the checking of all switchboard and station wiring diagrams. After a leave of absence from September 1925 until November 1926, Mr. Champe entered the company's investigations division, where he remained, first engaged in special studies of several affiliated systems covering system stability, operating methods, and system modernization; subsequently, serving as head of a division in charge of writing a-c machinery specifications. From February 1930 until June 1931, Mr. Champe was on the editorial staff of *The Electric Journal* (Westinghouse) first as associate editor and later as technical editor. In his $4^1/_2$ years on the Institute's editorial staff, Mr. Champe contributed in a substantial way to the development of ELECTRICAL ENGINEERING, and was responsible for certain divisions of the editorial work that could not have been handled satisfactorily without the technical training and the design and operating experience that he brought to and applied on the job. In his new work on the Consumers Power Company engineering staff, Mr. Champe will conduct miscellaneous technical studies, such as additions to system capacity, protective relay problems, and short circuit calculations.

H. B. GEAR (A'01, F'20, and director) who has been assistant to vice president, Commonwealth Edison Company, Chicago, Ill., has been elected vice president in charge of operating and engineering. Mr. Gear was born at Marietta, Ohio, and received the degree of bachelor of arts at Marietta College in 1892. Three years later he received the degree of mechanical engineer at Cornell University and entered the service of the Chicago Edison Company as electrical inspector. In 1900 he became chief inspector, and in 1911 was appointed engineer of distribution in the Commonwealth Edison Company. He was made assistant to vice president in 1921. Mr. Gear is the

author of several Institute papers, and his paper on diversity factor, published in 1910, is said to be the first on that subject to be published. He is also coauthor of a widely known book on electrical distribution. Since 1914 he has been a member of the Institute's committee on safety codes, serving as its chairman 1921–24, and since 1932 he has been a member of the technical program, Edison Medal, and Lamme Medal Committees. During the period 1923–27 he was a member of the Institute's standards committee, and he also has been representative on the electrical committee of the National Fire Protection Association (1921–24) and on the National Fire Waste Council (1923–24). In 1934 he was elected a director of the Institute.

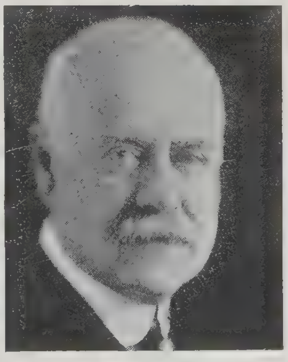
L. A. Ferguson (A'01, F'12, and past-president) vice president in charge of operating, construction, and electrical departments, Commonwealth Edison Company, Chicago, Ill., retired December 31, 1935. Mr. Ferguson graduated from the electrical engineering course at Massachusetts Institute of Technology in 1888, and entered the employ of the Chicago Edison Company in that year. He was made general superintendent of this company and the Commonwealth Electric Company in 1897, and in 1902 was elected second vice president of these 2 companies, which later were combined. Since 1914 he has held the position of the vice president, and has served also as a director of several other companies. Mr. Ferguson was president of the Association of Edison Illuminating Companies from 1901 to 1903, and was president of the former National Electric Light Association for the year 1902–03. He served the Institute as manager from 1904 to 1907, as vice president 1907–08, and as president 1908–09. During the period 1917–22 he was a member of the Institute's Edison medal committee, and since 1924 has been a representative on the commission of Washington Award. He is a member of the Western Society of Engineers and the Illuminating Engineering Society.

A. G. Schwager (A'24, M'31) formerly chief electrical engineer of the Pacific Electric Manufacturing Corporation, San Francisco, Calif., has been appointed chief engineer of that organization. A native of Switzerland (1899) Mr. Schwager completed his general and technical education and began his professional career in that country, first (1921–22) as technical assistant in the test laboratory of the Electric Manufacturing Company, at Oerlikon; subsequently (1922–23) as assistant to professor at his alma mater, the Institute of Technology in Zurich. He came to the United States in 1923, joining the staff of the Electrical Testing Laboratories in New York, as a technical assistant on high voltage cable research work, transferring his affiliation in 1924 to the New York Edison Company where he served as a draftsman on power plant and substation design. During 1925–26, he continued this same type of work with the Pacific Gas and Electric Company of San Francisco. Since 1926, Mr. Schwager has been affiliated continuously with the Pacific Electric Manufacturing Corporation, successively as test engineer in charge of the test laboratory, as executive engineer in charge of the engineering department, as oil circuit breaker design engineer in charge of oil circuit breaker design, and as chief electrical engineer. Mr. Schwager has contributed generously to contemporary technical literature, both through the trade press and through numerous papers presented before the A.I.E.E.

W. E. Holland (A'04, M'12) vice president in charge of engineering, Philadelphia Storage Battery Company, Philadelphia, Pa., has resigned as an officer and director of the company and is retiring from active business. He entered the business as a tester with the Edison Storage Battery Company in 1902, and shortly after was made chief of the battery experimental department. Mr. Holland was engaged in research work with the inventor, and was appointed chief electrical engineer of the Edison company at Orange, N. J., in 1911. Since 1918 he has been with the Philadelphia Storage Battery Company, and since 1925 has directed the radio developments of the company. He was chairman of the first radio safety standards committee appointed by the Associated Manufacturers of Electrical Supplies, and was instrumental in securing the adoption of effective and practical safety standards for radio receivers. He has also been director of the engineering division of the Radio Manufacturers' Association, and from 1925 to 1933 was a member of the Institute's committee on electrochemistry and electrometallurgy. Mr. Holland is the author of several technical papers on storage batteries.


H. B. GEAR


C. F. KETTERING


L. A. FERGUSON

W. R. G. Baker (A'19) former vice president, RCA-Victor division, RCA Manufacturing Company, Inc., Camden, N. J., has been appointed managing engineer of the radio receiver section of the General Electric Company at Bridgeport, Conn., with responsibility for engineering and manufacturing. A graduate of Union College, from which he received the degrees of bachelor of engineering, master of electrical engineering, and doctor of science, Doctor Baker was employed for several years by the New York Telephone Company, and had the title of equipment engineer during 1915–16. He then engaged in radio development work with the General Electric Company at Schenectady, N. Y., and subsequently was made designing engineer in charge of transmitters. His responsibility was enlarged in 1924 to include the design of all radio products, and 2 years later he was given charge of all radio development, design, and production. In 1929 he became connected with the then newly formed RCA-Victor Corporation as head of radio engineering activities, and later became general manager of the plant. During 1933–34 Doctor Baker was a member of the Institute's special committee on biographies and talking motion pictures, and he is now chairman of the engineering committee of the Radio Manufacturers' Association.

W. L. Abbott (A'01, F'13, and member for life) chief operating engineer, Commonwealth Edison Company, Chicago, Ill., retired on December 31, 1935. Mr. Abbott, who was born near Morrison, Ill., was graduated from the University of Illinois in 1884, and after employment with several companies became president and manager of the National Electric Construction Company in 1889. This company was purchased by the Chicago Edison Company in 1895, and Mr. Abbott was made chief engineer of one of the power houses. Four years later he became chief operating engineer for this company, a position which he has since held with this company and its successor, the Commonwealth Edison Com-Company. He is the author of numerous papers presented before engineering societies and is a member and past-president of The American Society of Mechanical Engineers, and a member and past-president of the Western Society of Engineers. From 1905 to 1923 he was a member of the board of trustees of the University of Illinois, serving as president of the board for 14 years. In 1929 the university granted him the honorary degree of doctor of laws.

A. R. Wellwood (M'22) who has been assistant director of the electric rate survey of the Federal Power Commission, Washington D. C., has been appointed director. Major Wellwood has been engaged in various branches of electric utility work since 1911, when he became assistant chief engineer of the Central Hudson Gas and Electric Company at Poughkeepsie, N. Y. In 1920 he resigned as district operating manager of the company to accept the position of assistant engineer secretary of the superpower survey of the U.S. Geological Survey, and the following year became

connected with the firm of Murray and Flood, consulting engineers in New York, N. Y. He has conducted statewide and regional surveys in many parts of the country, and has been chief engineer of the South Carolina Power Rate Investigating Comittee and chief consultant to the Public Service Commission of South Carolina.

O. E. Buckley (M'19, F'29) director of research, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed a member of the National Advisory Council on Applied Physics. The council, the formation of which was announced recently by the American Institute of Physics, is intended to stimulate the application of physics to other sciences and to industry. Mr. Buckley has been a member of the A.I.E.E. committee on electrophysics since 1926, serving as its chairman 1929–31, and is also a member of the committee on research.

W. C. Stevens (A'11, F'20) chief engineer of Cutler-Hammer, Inc., Milwaukee, Wis., has been advanced to the position of vice president in charge of engineering. Mr. Stevens graduated from Cornell University in 1906 and has been connected with the Cutler-Hammer Company almost continuously since that time. For many years he was a sales engineer, and was made sales manager at Milwaukee in 1917. Since 1924 he has devoted his time to engineering work, and for the past several years has been chief engineer.

M. J. Kelly (M'26, F'31) vacuum tubes and transmission instruments director, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed a member of the National Advisory Council on Applied Physics, the formation of which was recently announced by the American Institute of Physics to stimulate the application of physics to other sciences and to industry. Mr. Kelly has been a member of the A.I.E.E. committees on communication and standards since 1934, and recently was co-author of an Institute paper on vacuum tubes.

Harvey Fletcher (M'22, F'30) physical research director, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed a member of the National Advisory Council on Applied Physics, the formation of which was recently announced by the American Institute of Physics to stimulate the application of physics to other sciences and to industry.

O. S. Mitchell (A'23, M'30) editor of *Electrical News and Engineering*, Toronto, Ont., Can., has been appointed editorial director of Hugh C. MacLean Publications, Ltd., publishing a number of business newspapers including *Electrical News and Engineering*, *Electrical Appliances and Supplies*, and *Radio Trade Builder*.

J. B. MacNeill (A'18) former general manager of distribution engineering, Westinghouse Electric and Manufacturing Company, who has been at East Pittsburgh, Pa., and Boston, Mass., has returned to East Pittsburgh as manager of switchgear engineering. Mr. MacNeill, who is the author of several Institute papers, was a member of the Institute's committee on protective devices 1920–22, 1928–30, and 1931–32, and was a member of the power transmission and distribution committee 1933–35.

Wilfred Sykes (A'09, M'14) assistant to president, Inland Steel Company, Chicago, Ill., has been appointed a member of the alloys of iron research committee of Engineering Foundation. He has been a member of several Institute committees, serving for a number of years on the committee on applications to iron and steel production.

R. D. Kaul (A'32) who has been district engineer of the Garrison Engineering Corporation at Waterbury, Conn., has been appointed chief engineer with offices at Great Barrington, Mass. Mr. Kaul has been connected with the company in various capacities since 1927.

A. J. Williams, Jr. (A'27) chief of electrical division, research department, Leeds and Northrup Company, Philadelphia, Pa., has been appointed an Institute representative on the sectional committee on vacuum tubes for industrial purposes of the American Standards Association.

C. A. Mayo (A'13) manager of the Eastern Massachusetts Electric Company, Salem, has also taken over the position of assistant manager of the Beverly (Mass.) Gas and Electric Company. Mr. Mayo was a member of the Institute's committee on automatic stations 1930–32.

F. L. Ball (A'22, M'27) vice president, Charles H. Tenney and Company, Boston, Mass., has been designated as regional executive with managerial supervision of certain groups of operating companies in the New England Power Association.

H. L. Gordon (A'35) formerly designing engineer with the Rhodium Corporation of America, Brooklyn, N. Y., is now a member of the examining corps of the U.S. Patent Office, Washington, D. C.

Edward Lynch (A'27, M'35) meter engineer formerly with the General Electric Company of South America, is now with the General Electric Company at West Lynn, Mass.

G. J. Fiedler (A'32) recently was made an instructor in the electrical engineering department of Union College, Schenectady, N. Y.

Gabriel Heller (A'32) former graduate student at Columbia University, New York, N. Y., is now at Talladega College, Talladega, Ala.

P. L. Andry, Jr. (A'34) is now technical assistant in the engineering department of the Shell Petroleum Corporation, East Chicago, Ind.

G. H. Fett (A'32) is now in the department of electrical engineering at the University of Illinois, Urbana.

E. S. Jackson, Jr. (A'32) is again with the Consumers Power Company at Jackson, Mich.

W. W. Ensminger (A'34) recently accepted a position with the Columbus Manufacturing Company, Columbus, Ga.

R. A. Strothman (A'32) is now engaged by the Navy Department at Washington, D. C., as telephone and telegraph engineer.

D. H. Schell (A'35) is now employed by the General Electric Company at Bridgeport, Conn.

P. B. Thoresen (A'35) is now employed in the testing department of the Builders Iron Foundry, Providence, R. I.

P. E. Baker (A'33) is now with the Central Rubber and Supply Company, Indianapolis, Ind.

C. E. Bell (A'33) has accepted a position with The Converse Company, Inc., Seattle, Wash.

F. E. Levy (A'33) is now apprentice electrical tester with the Los Angeles (Calif.) Bureau of Power and Light.

D. R. Elmore (A'35) is now chief inspector at St. Louis, Mo., for the lamp testing service of Electrical Testing Laboratories.

Obituary

Bryce Eugene Morrow (F'35) chief engineer and manager of the production and transmission department, Consumers Power Company, Jackson, Mich., died January 4, 1936. He was an Associate of the Institute from 1904 to 1911. Mr. Morrow was born at Banbridge, Ireland, September 22, 1874. He attended public schools in Schenectady, N. Y., and in 1888 entered the employ of the Edison Machine Works in that city. Two years later he was transferred to the testing department, of which he became superintendent. During tests of the first a-c generator built at this plant, which later became the General Electric Company, Mr. Morrow assisted the late Thomas A. Edison (A'84, M'84, HM'28) and Dr. A. E. Kennelly (A'88, F'13, HM'33, Life Member, and past-president). In 1902 Mr. Morrow became manager of the Hudson River Power Transmission Company, a position which he resigned in 1912 to become chief engineer of the Utilities Mutual Insurance Company. Three years later he accepted the position of manager of production and transmission for the Consumers Power Company. Management of the electrical construction department was added to his duties in 1922, and in 1929 he was appointed chief engineer and manager of the production, transmission, and construction departments. During the 20 years he was with this company, a period in which the system capacity more than quadrupled, Mr. Morrow had charge of, and was directly responsible for, the operation of the entire generation and transmission system. He was a member of the Edison Pioneers, and had taken an active part in the affairs of the former National Electric Light Association.

William Anderson (A'20) professor of physics and electrical engineering, Rhode Island State College, Kingston, died December 27, 1935. He was born at Chanute, Kan., February 18, 1873, and attended Kansas State Agricultureal College, from which he received the degrees of bachelor of science and master of science in 1898 and 1906, respectively. Later, in 1911, Cornell University granted him the degree of master of arts. From 1900 to 1906 he taught at Kansas State Agricultural College, first as an assistant in mathematics and later as an instructor in physics and electrical engineering. In 1906 he became an instructor in the latter subjects at the Michigan College of Mines, and in 1912 was appointed assistant professor of mechanical engineering. Since 1919 he had been professor of physics and electrical engineering at Rhode Island State College. Professor Anderson was a member of the Society for the Promotion of Engineering Education and Sigma Xi.

Scott Lynn(A'13, M'15, F'29) president, Sangamo Company, Ltd., Toronto, Ont., Can., died January 1, 1936. He was born at Salt Lake City, Utah, on October 14, 1887, and received his technical education at the United States Naval Academy. In 1910 he first was employed by the Sangamo Electric Company of Springfield, Ill., leaving the position of assistant to the chief engineer in 1912 to work with mining and smelting companies in Utah for a short time. In 1913 he returned to the Sangamo Company in sales work, and established and managed the Rochester, N. Y., office, where he had charge of sales and engineering. Mr. Lynn organized the Sangamo Electric Company of Canada, Ltd., in 1917, and for a number of years was vice president and general manager with active charge of all manufacturing and design. He was a director of the Lincoln Meter Company, Inc., Springfield, Ill., and Lincoln Meter Company, Ltd., Toronto, and a member of the American Society of Mechanical Engineers and other associations, serving on committees of the Canadian Engineering Standards Association and the Canadian Electrical Association.

Jonathan Edwards Woodbridge (A'98 and member for life) consulting engineer, San Francisco, Calif., died December 23, 1935. Mr. Woodbridge was born at Duluth, Minn., January 30, 1872, and was graduated from the electrical engineering course at Massachusetts Institute of Technology in 1893. During the next few years he was employed by the Duluth and Superior Telephone Company and the Long Island Railroad, and in 1897 became associate editor of *Electrical World*, taking the position of editor the following year. In 1900 he undertook the duties of assistant to the chief of the railway engineering department of the General Electric Company, and in 1910 went to San Francisco as resident engineer for Ford, Bacon, and Davis. Between 1910 and 1933 he served as chief engineer of the Sierra and San Francisco Power Company and as consulting engineer for the Market Street Railway. He was a member of the Institute's protective devices committee 1915–16, and of the transmissions and distribution committee 1914–16 and 1918–20.

Edwin Andrew Diestler (A'35) development engineer with Albert S. Richey, Worcester, Mass., died July 11, 1935, according to word just received at Institute headquarters. He was born in Fergus County, Mont., May 23, 1893. From 1912 to 1919 he was employed by several engineering and appraisal firms, and served also in the U.S. Army. In 1919 he became connected with Hagenah and Erickson (later Victor A. Dorsey and Company) consulting engineers in Chicago, Ill., and was engaged in the supervision of cost and depreciation studies of power and railway properties in many cities of the central and southwest parts of the United States until 1931. Mr. Diestler then undertook similar work for the Public Service Commission of Missouri until 1933, following which he was employed for a short time by The Bemis Company, Chicago, Ill., and the Civil Works Administration before becoming associated with Albert S. Richey in 1934. Since then Mr. Diestler had been engaged in an analysis of records for the Public Service Company of Northern Illinois, the Commonwealth Edison Company, and the Chicago Surface Lines.

Claude W. Mitchell (M'31) chief electrical engineer, Board of Fire Underwriters of the Pacific, San Francisco, Calif., died November 27, 1935. He was born at Rockford, Ill., April 10, 1878, and was a graduate of the University of California, from which he received the degree of bachelor of science in 1902. In 1905 he was employed by the Board of Fire Underwriters of the Pacific as an electrical inspector, a position which he held until 1912 when he was made electrical engineer. Since 1927 he had been chief electrical engineer. Mr. Mitchell was for many years a member of the electrical council of the Underwriters' Laboratories, Inc., and of the electrical committee of the National Fire Protection Association. He took part in the preparation of the National Electrical Code, and was the author of a series of articles on electrical construction and interpretation of code rules, being well known as an authority on the code. Mr. Mitchell was a member of the Institute's committee on communication from 1931 to 1935.

William Alfred Harding (A'09) consulting mechanical and electrical engineer, Los Angeles, Calif., died on November 15, 1935. He was born at Bristol, England, June 17, 1864, and was educated in England. From 1889 to 1895 he was employed by various electric plants and railways at Seattle, Wash., and in British Columbia, and later was electrical engineer for railways at Chicago, Ill., Santa Barbara, Calif., and Los Angeles. During 1908–09 he was employed by the U.S. Reclamation Service, to which he returned in 1912 in connection with the Elephant Butte Dam in New Mexico. Following several years in private work he became mechanical superintendent, Celite Products Company, Los Angeles, 1920–23; in charge of the mechanical department, Southern California Edison Company, Big Creek, 1923–25; and foreman, electrical construction, Los Angeles Gas and Electric Company until he returned to private practice in 1926.

Philip Van Rensselaer Van Wyck (A'91 and member for life) former chief engineer of the Empire City Subway Company and more recently associated with Mackay and Company, New York, N. Y., died December 14, 1935. Mr. Van Wyck was born at Summit, N. J., May 27, 1868. He was engaged in the construction of the Richmond and Danville Railroad, and in 1888 was connected with the Nicaragua Canal Commission during the survey of the proposed site. Following his return to the United States he became chief engineer of the underground conduit company, a subsidiary of the New York Telephone Company. He was also a director of the Hamilton Gas Company and the Mutual Investment Trust Company, and recently had taken part in a number of philanthropic enterprises.

Willard Mortimer Smith (A'28) chief load dispatcher, Eastern Massachusetts Electric Company, Salem, Mass., died recently. He was born at Portland, Me., February 13, 1886, and entered the employ of the Cambridge (Mass.) Electric Light Company in 1907, being connected with different departments until 1911 when he entered the engineering department, in which he subsequently held various positions. In 1918 he was given charge of electrical operation and construction in the station and underground distribution, and in 1924 became chief load dispatcher of the Eastern Massachusetts Electric Company, organizing the load dispatching department of properties near Boston, Mass., some years ago.

Richard Koch (A'14) electrical engineer, Warwick, R. I., died September 16, 1935. He was born in Germany on March 27, 1875, and was educated there. From 1897 to 1908 he was electrical engineer with Allgemeine Electricitaets Aktiengesellschaft at Berlin and Dortmund, and from 1908 to 1912 was chief electrical engineer for the Bergmann Electricitaets Werke at Dusseldorf. In 1912 he became connected with the Concordia Electricataets Aktiengesellschaft at Dusseldorf, and 2 years later came to the United States as general manager of the Concordia Safety Lamp Company at Pittsburg, Pa. This company developed into the Concordia Electric Company, and Mr. Koch became vice president and technical manager, leaving the company in 1929.

Eskil Berg (A'95 and member for life) recently retired engineer of the General Electric Company, Schenectady, N. Y., died January 5, 1936. He was born in Sweden, and after graduation from the Chalmers Institute of Technology at Gothenburg came to the United States. During his association with the General Electric Company he worked for many years with the late Dr. C. P. Steinmetz (A'90, M'91, F'12, and past-president). Mr. Berg was connected with work on the steam turbine, on the development of electric ship propulsion, and on the mercury turbine. He was a member of the Institute's marine committee (now applications to marine work) from 1918 to 1922.

Membership

Recommended for Transfer

The board of examiners, at its meeting held January 22, 1936, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

DeForest, C. W., chief engr., Union Gas & Elec. Co., Cincinnati, Ohio.
Loew, E. A., prof. of E.E., and dean, coll. of engg., Univ. of Washington, Seattle.
Ready, L. S., cons. engr., 116 New Montgomery St., San Francisco, Calif.
Rogers, C. E., chief engr., Pacific Tel. & Tel. Co., Seattle, Wash.

4 to Grade of Fellow

To Grade of Member

Benson, F. S., asst. E.E., Pacific Gas & Elec. Co., San Francisco, Calif.
Berkner, L. V., physicist and E.E., Carnegie Institution of Washington, Washington, D. C.
Brown, G. R., development engr., Western Elec. Co., Kearny, N. J.
Brown, H. H., E.E., Wisconsin-Michigan Pwr. Co., Appleton, Wis.
Cave, P. W., mains cable engr., Macintosh Cable Co. Ltd., Derby, Eng.
Cunningham, A. J., E.E., Metropolitan Vickers Elec. Export Co. Ltd., Rio de Janeiro, Brazil, S. A.
deGoede, A. H., switchgear specialist, Gen. Elec. Co., New York.
Fouse, R. W., asst. to rate engr., N. Y. Edison Co. Inc., New York.
Freeman, W. G., central office apparatus engr., Bell Tel. Labs., Inc., New York.
Geary, T. W., telephone engr., Am. Tel. & Tel. Co., New York.
Glasier, R. C., development engr., Western Elec. Co., Inc., Kearny, N. J.
Hamilton, F. A., central station engg. dept., Gen. Elec. Co., Schenectady, N. Y.
Hunter, E. M., central station engg. dept., Gen. Elec. Co., Schenectady, N. Y.
Kellems, V., pres. and owner, Kellems Products Inc., New York.
Millard, A. M., engr. of transmission, Southern New England Tel. Co., New Haven, Conn.
Oberle, H., supt. of elec. distribution, Queens Borough Gas & Elec. Co., Far Rockaway, N. Y.
Quinn, W. J., elec. engr., Third Avenue Ry. Co., New York.
Sailer, L. R., instructor in elec. engg., Columbia Univ., New York.
Schaeffer, R., resident elec. engr., Oklahoma Gas & Elec. Co., Oklahoma City.
Skeats, W. F., in charge, circuit breaker interrupting capacity testing plant, Gen. Elec. Co., Schenectady, N. Y.
Stoddard, A. D., vice president and chief engr., Halliburton Oil Well Cementing Co., Duncan, Okla.
Sullivan, G. L., dean, coll. of engg., Univ. of Santa Clara, Calif.
Sundius, H. W., engr. of elec. co-ordination, Southern New England Tel. Co., New Haven, Conn.
Wurzbach, H. A., division training supervisor, Am. Tel. & Tel. Co., Denver, Colo.

24 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Feb. 29, 1936, or Apr. 30, 1936, if the applicant resides outside of the United States or Canada.

Adamek, W. E., Jr., Fisher Body Corp., Pontiac, Mich.
Amador, F. J., Jr., New Mexico State Col., State College.
Avavosis, J. S., 851 N. Parkside Ave., Chicago, Ill.
Backenstoss, H. B., Anaconda Wire & Cable Co., Hastings-on-Hudson, N. Y.
Ball, D. J., 373 Park Ave., Leonia, N. J.
Ballard, L. W., Jr., Gen. Elec. Co., Schenectady, N. Y.
Barker, O. (Member), Brooklyn Edison Co., Inc., N. Y.
Bauman, C. A., Pocahontas Fuel Co. Inc., Cleveland, Ohio.
Beeson, N. W., 230 Rockwood Ct., San Antonio, Texas.
Bhattacharjee, S. B., W. P. A. Projects, New York, N. Y.
Billman, L. S., Brooklyn Edison Co. Inc., N. Y.
Bird, J. C., Okonite Co., Seattle, Wash.
Blenden, H. A. (Member), Southwestern Bell Tel. Co., St. Louis, Mo.
Brauer, F. A., So. New England Tel. Co., New Haven, Conn.
Breidenbach, F. F., Indiana Bell Tel. Co., Indianapolis.
Brown, R. P., Southwestern Bell Tel. Co., Dallas, Texas.
Brown, R. R., N. C. State Coll., Raleigh.
Buchanan, W., Brooklyn Edison Co., Inc., N. Y.
Buchanan, W. A. (Member), Appalachian Elec. Pwr. Co., Welch, W. Va.
Buhler, J. S., Underwriters Laboratories, New York, N. Y.
Caldwell, J. S., Brooklyn Edison Co., Inc., N. Y.
Campbell, J. B., P. O. Box 533, New Canaan, Conn.
Capelli, S. W., Pub. Serv. Co. of Colo., Denver.
Carlin, P. J., Fla. Pwr. & Lt. Co., Miami.
Carter, G. K., Univ. of Va., University.
Carter, G. T., 1422 Rockland St., Calumet, Mich.
Christensen, G. F., Utah Pwr. & Lt. Co., Provo.
Clark, R. W., Maghavox Co., Ltd., Ft. Wayne, Ind.
Coffey, G. M., Emerson Elec. Mfg. Co., St. Louis, Mo.
Collard, A. R., New York Edison Co., Inc., N. Y.
Crawford, C. D., Modesto Irrigation Dist., Modesto, Calif.
Dailey, J. H., 201 Taylor Ave., Canastota, N. Y.
Davies, W. M., Houston Ltg. & Pwr. Co., Texas.
Day, A. B., Idaho City, Idaho.
Debowski, S., Brooklyn Edison Co., Inc., N. Y.
Dell, C. A. O., Niagara Falls Pwr. Co., Niagara Falls, N. Y.
Doon, H. H., New York Edison Co., Inc., N. Y.
Dunbar, O. C., Santa Fe Ice & Precooling Plant, San Bernardino, Calif.
Dzwonczyk, V. L., Diehl Mfg. Co., Elizabethport, N. J.
Eaden, N., Pacific Tel. & Tel. Co., Spokane, Wash.
Einwechter, W. S., Philadelphia Elec. Co., Pa.
Falcione, A. M., 128 Shawmut Ave., Boston, Mass.
Farnham, S. B., Gen. Elec. Co., Schenectady, N. Y.
Farrow, A. P., Tenn. Pub. Serv. Co., Knoxville.
Feingold, S., N. Y. Fire Dept., New York, N. Y.
Foca, A. R., New York Edison Co., Inc., N. Y.
Gallic, R. A., 574—78th St., Brooklyn, N. Y.
Gardner, W. C., Blacksville, W. V.
Garrabrant, F. O. (Member), Climax Molybdenum Co., Climax, Colo.
Gawlowicz, B. S., Brooklyn Edison Co., Inc., N. Y.
Green, M. I., 611 Isett Ave., Wapello, Iowa.
Grigsby, J. M., Modesto Irrigation District, Modesto, Calif.
Halman, T. R., Detroit Edison Co., Mich.
Ham, R. F., Brooklyn Edison Co., Inc., N. Y.
Hammond, R. E., Jr., Northern States Pwr. Co., Minneapolis, Minn.
Harvey, D. A., Mo. Pub. Serv. Comm., Jefferson City.
Henning, E. S., 3 Blaine Ave., Worcester, Mass.
Hill, R. C., So. Charleston, Ohio.
Hodgson, A. O. (Member), United Shipbuilding & Dry Dock Corp., Mariners Harbor, N. Y.
Hogan, B. W., Am. Tel. & Tel. Co., Washington, D. C.
Hurley, J. F. (Member), Brooklyn Edison Co., Inc., N. Y.
Ingalls, L. T., Brooklyn Edison Co., Inc., N. Y.
Johnson, James O., U.S. Navy Yard, Brooklyn, N. Y.
Johnson, John O., Bell Tel. Lab. Inc., New York, N. Y.
Joice, J. P., Royal Indemnity, New York, N. Y.
Jones, J. C., Fla. Pwr. & Lt. Co., Ft. Pierce.
Kamin, N. H., Intl. Business Machines Corp., Akron, Ohio.
Kaufman, H. S., Brooklyn Edison Co., Inc., N. Y.
Keepers, G. S., Champlin Refining Co., Enid, Okla.
Keiber, W. C., Jr., 201 North 10th St., Easton, Pa.
Kent, S. G., Fla. Pwr. & Lt. Co., Miami Beach.
Kimball, J. J., Brooklyn Edison Co., Inc., N. Y.
Kipp, L. H. (Member), Water Users, Phoenix, Ariz.
Klippel, O. H., 2947 Lister, Kansas City, Mo.
Komm, H. H., 1314a Shawmut Place, St. Louis, Mo.
Lansberg, W. A., Brooklyn Edison Co., Inc., N. Y.
Less, H., 9 Alden St., Boston, Mass.
Levy, C. G., Canadian Gen. Elec. Co., Toronto, Ont.
Light, L., 765 Hendrix St., Brooklyn, N. Y.
Livingston, H. R., Farr Alpaca Co., Holyoke, Mass.
Lowens, M., Bd. of Transportation of N. Y. C., N. Y.
Lyman, T. B., Pacific Manifolding Book Co., Emeryville, Calif.
Mader, S. C., Schools of Morgan Co., Jacksonville, Ill.
Margossian, M. A., Whitthorne & Swan Portrait Studio, Oakland, Calif.
Marsh, P. F., Schenectady Collegiate Center, N. Y.
Masheroni, J., 42-02—64th St., Woodside, N. Y.
Mason, T. C., Southwestern Lt. & Pwr. Co., Lawton, Okla.
Mathes, K. N., Gen. Elec. Co., Schenectady, N. Y.
Maxcy, D. J., Jr., New York Edison Co., Inc., N. Y.
McAdam, L. O., Southwestern Bell Tel. Co., Dallas, Texas.
McConnell, A. J., Gen. Elec. Co., Philadelphia, Pa.
McCreary, W. H., Brooklyn Edison Co., Inc., N. Y.
McKinley, J. T., P. O. Box 483 Ada, Okla.
McKinney, E. G., Okla. Gas & Elec. Co., Oklahoma City.
Meade, K. Q., Harder Refrigerator Corp., Cobleskill, N. Y.
Meadowcroft, F. H., Paraffine Companies Inc., Emeryville, Calif.
Meale, W. V., Fisher Body Co., Norwood, Ohio.
Miller, C. G. (Member), Bell Tel. Lab. Inc., New York, N. Y.
Miller, R. H., San Joaquin Lt., & Pwr. Corp., Reedley, Calif.
Millington, J. W., Sun Oil Co., Beaumont, Texas.
Mock, W., Radio Experimenter's Club Ltd., Regina, Sask., Can.
Moore, J. K., Hydro Elec. Comm., Salem, Ore.
Moore, R. W., Jr., Landis Tool Co., Waynesboro, Pa.
Myers, R. P., 10405 Ostend Ave., Cleveland, Ohio.
Newberry, E. S., Conn. Valley Pwr. Exchange, Hartford, Conn.
Nichols, C., Leeds & Northrup Co., Philadelphia, Pa.
Nixon, J. A., Southern New England Tel. Co., New Haven, Conn.
Noest, J. G. (Member), Brooklyn Edison Co., Inc., N. Y.
O'Brien, W. M., Northwestern Elec. Co., Rainier, Ore.
Osten-Sacken, I. C. (Member), Bell Tel. Lab. Inc., New York, N. Y.
Pardo, R. B., Pacific Tel. & Tel. Co., Seattle, Wash.
Parlour, G. S. (Member), c/o Eugene F. Phillips Elec. Wks. Ltd., Hamilton, Ont., Can.
Parsons, R. J., Brooklyn Edison Co., Inc., N. Y.
Pearce, C. T., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Pearson, H. R., Dallas Pwr. & Lt. Co., Texas.
Peirce, S. D., Gen. Radio Co., Cambridge, Mass.
Peters, E. F. L., Falstaff Brewery Corp., St. Louis, Mo.
Peterson, J. D., Charles Cory Corp., Brooklyn, N. Y.
Peterson, W. E., Consumers Pwr. Co., Jackson, Mich.
Piccardo, J. E., 4381 Lincoln Ave., Oakland, Calif.
Pillsbury, A. H., 3026 Oak St., Jacksonville, Fla.
Prinsloo, W. J. O., Brooklyn Edison Co., N. Y.
Rehagen, E. S., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.
Reichel, H. W. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Rennecamp, C. C. W., 5471 Oriole Ave., St. Louis, Mo.
Ricker, E. A., Univ. of Toronto, Ont., Can.
Robison, R. L., Star Machy. Co., Seattle, Wash.
Rummler, W. E., Otis Elevator Co., Yonkers, N. Y.
Rust, L. J. (Member), Pub. Serv. Comm. of Wis., Madison.
Sattinger, I. J., 2712 Brentwood Ave., Toledo, Ohio.
Schell, R. E., W. R. Grasle Elec Co., Portland, Ore.
Schmitz, R. C. (Member), Am. Transformer Co., New York, N. Y.
Schwarz, W. A., Chandeysson Elec. Co., St. Louis, Mo.
Shank, R. E., Indiana & Michigan Elec. Co., South Bend, Ind.
Shevalier, D. C., Montana Pwr. Co., Great Falls, Mont.
Shultes, C. K., West Berne, N. Y.
Simon, J. L., Okla. Mineral Survey, Clinton.
Spangenberg, K., Rose Poly. Inst., Terre Haute, Ind.
Specht, W., Gen. Elec. Co., Philadelphia, Pa.
Smart, H. W., Brooklyn Edison Co., Inc., N. Y.
Smith, E. L., Firestone Tire & Rubber Co., Akron, Ohio.
Smith, G. M., Miami Broadcasting Co., Fla.
Stevens, S. S., Transcontinental & Western Air Co., Kansas City, Mo.
Stremlau, D. Z., Conn. Valley Pwr. Exchange, Hartford, Conn.
Taylor, R. S., Okla. Gas & Elec. Co., Oklahoma City.
Thomas, E. U., Union Switch & Signal Co., Swissvale, Pa.
Tinley, E. S., 139 S. 15th St., Allentown, Pa.
Van der Berg, A. J., 285 Riverside Drive, New York, N. Y.
Van Eps, C., 1198 Ardsley Rd., Schenectady, N. Y.
Watt, D. H., Water Plumbing Air Conditioning & Elec. Co., Tulsa, Okla.
Wells, A. W., Los Angeles Railway Corp., Calif.
Welman, G. A., Gen. Elec. X-Ray Corp., New Orleans, La.
Weyrick, P. M., Mathews Conveyer Co., Ellwood City, Pa.
Whetstone, R. A., Elec. Storage Battery Co., Philadelphia, Pa.
White, W. E., Union Gas & Elec. Co., Cincinnati, Ohio.
Williams, H. A. (Member), Struthers Dunn, Inc., Philadelphia, Pa.
Wismer, A. R., Reno Gold Mines, Salmo, B. C., Can.
Witte, W. J., Con. Gas Elec. Lt. & Pwr. Co., Baltimore, Md.
Wolf, C. A., Jr., 166 Stone Ave., Yonkers, N. Y.
Wollgast, L. A., Detroit Edison Co., Detroit, Mich.

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Foreign

Babb, R. J., Westinghouse Elec. Intl. Co., Mexico, D. F., Mex.
Baca, A., Westinghouse Elec. Intl. Co., Mexico, D. F., Mex.
Denholm, N. H., North-Eastern Elec. Supply Co., Ltd., Newcastle-upon-Tyne, 4, Eng.
Hubard, E., Apt. Postal 1194, Mexico, D. F., Mex.
Mehta, P. L., 66 K. V. Substa., Lyallpur, Punjab, India.
Ramamurty, B., Vizgapatam Elec. Sup. Corp., Vizagapatam, India.
Singh, B., P. W. D. Elec. Branch, Punjab, India.
Ugalde, J., Saltos del Duero, Bilbao, Spain.

8 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Blanc, Victor, 153 Boulevard Lefebvre, Paris, France.
Crite, Mitchel, 32 E. 126th St., New York, N. Y.
Ghosh, K. C., c/o Compagnia Generale Di Elettricity, 34 Via Borgognone, Milan, Italy.
Hanker, Fred C., 303 Le Roi Road, Pittsburgh, Pa.
Kummer, Emil F., Box 898, Bridgeport, Conn.
Patel, Ishvarlal B., 5 Second Carpenters St., Bombay, 4, India.
Soskin, Samuel B., 1141 S. Central Park, Chicago, Ill.
Spiegel, William F., 7 Stegman Court, Jersey City, N. J.

8 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

HANDBOOK of CHEMISTRY and PHYSICS a Ready-Reference Book of Chemical and Physical Data. 20 ed. ed. by C. D. Hodgman. Chemical Rubber Pub. Co., 1935. 1951 p., tables, 7x4 in., lea., $6.00. New edition of a handbook for chemists and physicists, including in the revisions the sections on X ray spectra and on photometry.

MACHINERY'S YELLOW-BACK SERIES. N. Y. Machinery, 148 Lafayette St., 1935. 14 to 22 p., illus., 5½x8½ in., $.15 each; 8 for $1.00. A series of 50 pamphlets, each of which discusses a specific topic, including advice on electric motors, change gears, patents, plastics, steels, welding, brazing, etc.

MAKING a LIVING in RADIO. By Z. Bouck. N. Y. and Lond., McGraw-Hill Book Co., 1935. 222 p., illus., 8x6 in., cloth, $2.00. A survey of the opportunities, required training, and the problem of getting a position.

THE METAL—IRON. (Alloys of Iron Research, Monograph Series.) By H. E. Cleaves and J. G. Thompson. Published for the Engineering Foundation by McGraw-Hill Book Co., N. Y., 1935. 574 p., illus., 9x6 in., cloth, $6.00. A review of the available information on the preparation and properties of metallic iron of high purity including an extensive select bibliography.

METHODS of MEASUREMENT of DIELECTRIC CHARACTERISTICS at COMMERCIAL FREQUENCIES, by J. B. McCurley. A reprint from the *Proceedings* of the American Society for Testing Materials, Phila., v. 35, pt. 2, 1935. 17 p., illus., 9x6 in., paper, $.17. Describes a modification of the Doyle and Salter transformer bridge which offers a rapid, reasonably accurate method for determining dielectric characteristics; and a modified Schering bridge. The methods of operation are discussed, the mathematical treatment is outlined, and some experimental results are reported.

SOUND, an Elementary Textbook on the Science of Sound and the Phenomena of Hearing. By F. R. Watson. N. Y., John Wiley & Sons, 1935. 219 p., illus., 9x6 in., lea., $2.50. A nonmathematical treatment of acoustic phenomena devoted to the mechanical actions of sounding bodies and the physiological and psychological responses in hearing.

1935 SUPPLEMENT TO BOOK of A.S.T.M. STANDARDS. Phila., American Society for Testing Materials. 1935. 208 p., illus., 9x6 in., paper, $1.50 (to members $1.00). A second supplement to the 1933 book of A.S.T.M. standards, containing 36 standards which were adopted or revised in September 1935.

TASCHENBUCH für SCHIFFSINGENIEURE und SEEMASCHINISTEN. By E. Ludwig. Munich and Berlin, R. Oldenbourg, 1935. 633 p., illus., 7x4 in., cloth, 12 rm. A pocketbook for marine engineers which includes electrical equipment.

Deutsches Museum Abhandlungen und Berichte, Jg. 6, Heft 4. RÖNTGEN und SEINE ENTDECKUNG, by P. Debye. Berlin, VDI-Verlag, 1934. 103 p., illus., 8x6 in., paper, 90 rm. A biographical address delivered at the annual meeting of the Deutsches Museum, May 7, 1934.

ANALYTICAL and APPLIED MECHANICS. By C. R. Clements and L. T. Wilson. N. Y. and Lond., McGraw-Hill Book Co., 1935. 420 p., illus., 9x6 in., cloth, $3.75. Aims to provide a thorough first course in mechanics, and to present a wide variety of applications, together with many problems.

DIESEL and Other Internal-Combustion Engines. By H. E. Degler. Chicago, American Technical Society, 1935. 237 p., illus., 9x6 in., cloth, $2.50. A brief, practical account of the development of these engines, adapted to the needs of owners and operators.

ANECDOTAL HISTORY of the SCIENCE of SOUND, to the Beginning of the 20th Century. By D. C. Miller. N. Y., Macmillan Co., 1935. 114 p., illus., 9x6 in., cloth, $2.50. An informal record of the principal events in the history of sound, bringing together much widely scattered information.

COLLEGE PHYSICS. By C. E. Mendenhall, A. S. Eve, D. A. Keys. Boston, N. Y. and Lond., D. C. Heath and Co., 1935. 592 p., illus., 9x6 in., cloth, $3.76. A text for an introductory course in physics for university or junior college students, with mathematical requirements reduced to a minimum.

COMMUNICATION NETWORKS. v. 2. The Classical Theory of Long Lines, Filters, and Related Networks. By E. A. Guillemin. N. Y., John Wiley & Sons, 1935. 587 p., illus., 9x6 in., cloth, $7.50. Intended to present a thorough treatment of the transmission line as a communication facility, this volume leads into the field of filter theory and its related problems, pertaining more generally to network theory as a whole, and applies to the power as well as the communication aspects.

DRAFTING for ENGINEERS. By C. L. Svensen. 2 ed. N. Y., D. Van Nostrand, Co., 1935. 554 p., illus., 10x6 in., cloth, $3.00. A comprehensive course of instruction, based on present industrial and professional standards, covering the entire field of engineering drawing, with chapters on certain special subjects.

ELECTRIC MELTING PRACTICE. By A. G. Robiette. Phila., J. B. Lippincott Co., 1935. 324 p., illus., 9x6 in., lea., 15s ($7.50). Considers the electric furnace from the point of view of the practical metallurgist, offering a review of current practice in electric melting by various methods.

ELECTRICAL MEASUREMENTS in Principle and Practice. By H. C. Turner and E. H. W. Banner. Pittsburgh, Instruments Publishing Co., 1935. 354 p., illus., 9x6 in., cloth, $4.50. Intended primarily for engineers making occasional electrical measurements, the book gives a general account, without mathematical and theoretical matters, of the types of measurements and instruments.

KURZSCHLUSSSTRÖME in DREHSTROMNETZEN, Berechnung und Gegrenzung. By M. Walter. Munich and Berlin, R. Oldenbourg, 1935. 146 p., illus., 10x7 in., paper, 6.50 rm. A systematic account of short-circuit phenomena, the varieties of short circuits, their effects, and the methods of protection.

MESSBRÜCKEN und KOMPENSATOREN. Bd. 1. Theoretische Grundlagen. By J. Krönert. Munich and Berlin, R. Oldenbourg, 1935. 282 p., illus., 10x7 in., cloth, 13.80 rm. Intended as a reference book for the designer and maker of measuring bridges and potentiometers, the book aims to cover the various types in practical use, to provide a systematic account of basic theory and to give a survey of present developments.

MODERN RADIO ESSENTIALS. By K. A. Hathaway. Chicago, American Technical Society, 1936. 200 p., illus., 9x6 in., cloth, $2.00. An elementary, nonmathematical account of the fundamental theory and the essential principles of transmitting and receiving instruments.

PREPARATION of ENGINEERING REPORTS. By T. R. Agg and W. L. Foster. N. Y. and Lond., McGraw-Hill Book Co., 1935. 192 p., illus., 8x5 in., cloth, $1.75. Discusses the collection of data, arrangement of subject matter, style, illustrations, and other practical matters.

RADIO ENGINEERING HANDBOOK. Ed. by K. Henney. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 850 p., illus., 7x5 in., lea., $5.00. A thorough revision of the former edition to cover recent advances in radio engineering, intended primarily to provide a convenient compilation of the data required by the designer and operating engineer.

STEAM PLANT OPERATION. By E. B. Woodruff and H. B. Lammers. N. Y. and Lond., McGraw-Hill Book Co., 1935. 368 p., illus., 8x6 in., cloth, $3.00. Provides a knowledge of the fundamental principles of stationary engineering, with approved methods of operating all the equipment usually found in power plants.

BOOK of A.S.T.M. TENTATIVE STANDARDS Issued Annually, 1935. Phila., Am. Society for Testing Materials, 1935. 1591 p., illus., 9x6 in., cloth, $8.00; paper, $7.00. Contains 290 specifications, methods of testing, definitions, and recommended practices which have been proposed as standards, but not yet so adopted, for many materials, including insulation.

DAMPF TURBINEN KRAFT WERKE KLEINER und MITTLERER LEISTUNG. By F. Aschner. Berlin, Julius Springer, 1935. 145 p., illus., 9x6 in., cloth, 9 rm. Considers the construction of steam turbine electric plants with reference to the requirements of the smaller installations.

DIESEL ENGINEERING HANDBOOK. ed. by L. H. Morrison. de luxe ed. N. Y., Diesel Publications, Inc., 1935. 831 p., illus., 9x6 in., leather, $5.00. Provides practical information upon the operation and maintenance of Diesel engines.

F. H. RICHARDSON'S BLUEBOOK of PROJECTION, Sound Section in Collaboration with Aaron Nadell. By F. H. Richardson. 6 ed. N. Y., Chicago, Lond., Paris, Quigley Pub. Co., 1935. 709 p., illus., 9x6 in., leather, $5.00 (by mail $5.25). An exposition of motion picture projection, including sound reproduction.

TRANSIT ENGINEERING, Principles and Practice. By J. K. Tuthill. Planographed and published by John S. Swift Co., St. Louis, Chicago, N. Y. 1935. 334 p., illus., 11x8 in., paper, $4.50. A textbook account of electric railway practice, including power generation and distribution, motors, brakes, cars and car equipment, feeder systems, train control, electric locomotives, gasoline, oil-electric and other self-propelled cars and trains, and motor and trolley omnibuses.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Business Attributable to New Developments.—Indicating the importance of sustained industrial research, an analysis for the five depression years 1930–1934 shows that the ratio between business attributable to "new" lines of products (that is, lines not manufactured more than ten years prior to the year under consideration) and total business for all lines manufactured by the General Electric Company, was, on the average, approximately 10 per cent *higher* than for the five prosperity years 1926–30. Being based on entire lines, the above analysis excludes many important new developments within lines manufactured more than ten years prior to the year under consideration. The analysis, therefore, is on the conservative side.

Empire Sheet & Tin Plate Promotions.—According to a recent announcement, Stanley A. Richardson has been appointed general sales engineer of the American Sheet & Tin Plate Co., Mansfield, O. For the past 5 years Mr. Richardson has served as chief metallurgist. Glenn L. Bierly has been appointed general purchasing agent and assistant treasurer of the company. He was previously auditor and comptroller.

Tin Consumption Increased.—The January issue of the International Tin Research and Development Council's Bulletin published by The Hague Statistical Office gives some prelimiary figures of tin production and consumption in 1935. World production was 138,000 tons and consumption was 142,000 tons in the calendar year 1935, compared with 108,637 tons and 117,681 tons, respectively, in 1934. Although the consumption figures show an encouraging increase of 20% over 1934 they are still considerably lower than the record level of 178,028 tons reached in 1929. Considering the twelve month period ended November 1935, the only country for which there is an appreciable decrease in consumption is France, and this may be due to the transfer of the Saar from France to Germany in February 1935. The increase of 11.9% in Germany was almost exactly equivalent to the decrease in France. Notable increases are recorded for U.S.A. 34.7%, Russia 27.6%, and Italy 42.3%.

New Automatic Potentiometer.—An automatic potentiometer in which the balancing circuit is continuously and rapidly adjusted by photoelectric control has been announced by the Weston Electrical Instrument Corp., Newark, N. J. The instrument provides a highly sensitive means for indicating or recording voltage or current at ranges as low as 2 millivolts or 5 microamperes full scale, or even lower if required. Temperature, pH values, or other physical quantities convertible to electrical terms may be indicated, recorded or controlled with a speed and precision hitherto unattainable in dealing with the minute electrical input encountered in many such applications. The instrument furnishes an indicating current capable of operating a number of meters, recorders, control relays, etc.

New Connectors.—A new line of clamp type connectors, known as the V-line, has been announced by the Burndy Engineering Co., Inc., New York. The basis of design in this group of connectors for wire and cable is the use of a Durium U-bolt which, by the forging process, is broadened at the clamping area. The advantage of this type of connector is that each clamping element can accommodate a wide range of cable sizes and yet, because of the broad pressure area, will not injure the cable strands. Durium, of which the U elements are made, is a special copper alloy having an ultimate tensile strength greater than steel and, at the same time, it will not corrode or season crack. The V-line of clamp connectors can, therefore, be used along the seacoast and in corrosive industrial atmospheres. All forms of connectors are available for conductors ranging from No. 8 stranded to 2,000,000 CM.

Impulse Oil-Blast Circuit Breakers.—The impulse oil-blast principle, basis of the design of the spectacular 287,500-volt circuit breakers built by General Electric for the Boulder Dam lines, has been applied to 138,000-volt service. Four such triple-pole breakers have been furnished by G-E to the Bureau of Power and Light of the City of Los Angeles, for installation at the station where 287,500-volt power coming from Boulder Dam is stepped down to 138,000 volts. Like the larger FG-30 type, the new FG-20 breaker is radically different in appearance, and a long step forward in performance. The breaker will open a circuit in a twentieth of a second (three cycles) from the time the high-speed trip relay is energized; 138,000-volt circuit breakers heretofore built have required about an eighth of a second (eight cycles). A triple-pole FG-20 breaker contains only 1100 gallons of oil, less than a quarter of the 4700 gallons required for a conventional eight-cycle breaker having the same interrupting rating.

Trade Literature

Tachometers.—Bulletin 935, 4 pp. Describes electrical indicating and recording tachometers. The Esterline-Angus Co., Indianapolis, Ind.

Electric Furnaces.—Bulletin, 20 pp. Describes Heroult 3-phase electric furnaces, one-half to 100 tons capacity. Installations and schematic layouts are illustrated. American Bridge Co., Frick Bldg., Pittsburgh, Pa.

Asbestos-Covered Conductors.—Catalog, 16 pp. Describes asbestos insulated wires and cables; gives specifications, engineering data, and illustrated construction details. National Electric Products Corp., 1215 Fulton Bldg., Pittsburgh, Pa.

New Gear-Motors.—The Wagner Electric Corp., St. Louis, has developed a line of fractional-horsepower gear-motors suitable for direct connection to equipment requiring special speeds. They are available in single-reduction and double-reduction types, with speeds as low as 6 rpm.

Diesel Generator Sets.—Bulletin, 4 pp. Describes Diesel electric direct-connected generator sets, consisting of a Diesel engine equipped with auxiliary fuel pump, connected to an electric generator; available in 25, 40, and 60 kw units, in a-c or d-c models. Caterpillar Tractor Co., Peoria, Ill.

Mercury Vapor Lamp Fixtures.—Bulletin 256, 28 pp. Describes the new 400 watt, high-intensity, mercury vapor lamp for various types of interior and exterior illumination. Includes complete data, illustrations, dimensions and list prices on lighting fixtures for this lamp. Benjamin Electric Mfg. Co., Des Plaines, Ill.

Service Cable.—Bulletin GEA-1791B, 12 pp. Describes rubber-insulated, service cable for installation from pole line to and into buildings. Includes overhead, tamperproof, unarmored and armored non-tamperproof types; and underground, armored "Parkway" types, metallic and nonmetallic. General Electric Co., Schenectady, N. Y.

Insulators.—Bulletin 123, 12 pp. Describes line post and station post insulators. Includes drawings, photographs, and a comprehensive technical discussion of the characteristics of these new developments; also, reports of numerous tests, and installation illustrations. Lapp Insulator Co., Inc., Le Roy, N. Y.

Electric Furnaces.—Catalog "Modern Melting," 48 pp. Contains general melting information, a catalog of various rocking arc furnaces, and a section for auxiliary furnace and foundry equipment. A section of special interest to power companies is a feature. Detroit Electric Furnace Co., 825 W. Elizabeth St., Detroit, Mich.

Smoke-Density Recorder.—Catalog N-93 12 pp. Describes the "Micromax" smoke density recorder, which measures smoke density at the stack, indicates and records it on a large dial wherever needed, and signals major changes if desired. In this equipment two streams of stack gas are continuously drawn through widely separated inlets by an aspirator and merged in a sampling chamber. Through the entire length of this moving sample, radiation passes from an electric lamp at one end to a thermopile at the other. This radiation, falling on the thermopile in inverse proportion to the density of the smoke sample through which it passes, generates an electromotive force (voltage) which is measured by the Micromax recorder. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.